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# *Art. I.—The Tertiary Geology of Australia.*

By F. A. SINGLETON, D.Sc.

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## Contents.



## Introduction.

At a symposium on Tertiary Formations of the Pacific Region at the First Pan-Pacific Scientific Conference (Honolulu, 1920), an account of the Post-Cretaceous Rocks of Australia was given by Richards (15). At the Second Congress (Australia, 1923), Chapman and Singleton (27) contributed a more detailed paper on the Tertiary Deposits of Australia, a supplementary note to which was furnished to the Fourth Congress (Java, 1929) by the author (43).

In the past decade not only have undoubted Eocene deposits been identified in Australia, but also considerable changes have taken place in the views of the joint authors above-mentioned, and their account no longer represents the views of either of them. Consequently the time seems ripe to offer an account of the present state of our knowledge of the Tertiary Geology of the Commonwealth of Australia, including Tasmania but not New Guinea.

The present paper seeks to cover a wider field than either of the preceding accounts, necessarily in outline only, so that for details the papers listed in the bibliography should be consulted.

## Geographic Distribution.

Of the three million square miles, in round figures, of the continent of Australia, marine Tertiary formations occupy about $6\frac{1}{4}$ per cent., of which outcrops are subordinate to areas in which they are covered by later deposits or by igneous rocks.

They form a discontinuous fringe from lat. 21° 46′ S., long. 114° 6′ E. at North-West Cape in West Australia, along the western and southern coasts of the continent to lat. 37° 50′ S., long. 148° 5′ E. near Lakes Entrance in Victoria, with small areas on the north-west coast of the island of Tasmania and on the islands of Bass Straits. While their occurrence is chiefly along a coastline of about 5,000 miles, they are found inland for 250 miles in the basin of the Murray River, where they extend into New South Wales, and perhaps nearly as far in the little-known region north of the Great Australian Bight. Over this vast area, extending nearly 1,350 miles north to south and 1,750 miles east to west, virtually nothing but reconnaissance work has been done except in the more populous areas of the south-east, in the States of South Australia, Victoria, and Tasmania, where the studies of a limited band of workers over the past three-quarters of a century have accumulated a considerable literature, both stratigraphical and palaeontological.

Non-marine deposits are more widespread, notably in the interior of the continent, but can seldom be satisfactorily dated except in the south-east, where they come into relation with marine deposits or with igneous rocks whose age is otherwise determinable. Elsewhere, particularly when unfossiliferous, it is seldom possible to subdivide them or even to distinguish them from post-Tertiary deposits.

Igneous rocks are more particularly developed in Eastern Australia from Queensland to Tasmania, but again it is difficult to draw the boundary between Tertiary and Quaternary igneous activity, and it has not always been possible to do so on the map. More precise definition of age, by interrelation with marine deposits, is practically confined to Victoria, and in the other States physiographic evidence must be relied upon.

It will be seen that even the areal distribution of the Tertiary rocks is but imperfectly known, and it follows that the boundaries shown on the map must necessarily be accepted as tentative, as must, indeed, be regarded much of the account which follows.


MAP 1.

Geological Map of Australia and Tasmania, showing distribution of Tertiary Rocks. Modified from geological map of the Commonwealth (2) and State geological maps

## Classifications of the Marine Deposits.

The Tertiary controversy in Australia has undergone such kaleidoscopic changes and is so far, even now, from finality that it is difficult for one unfamiliar with its detailed history to understand the literature. Consequently it seems desirable, before outlining the present views of the writer, to give a brief historical account to supplement those given by Pritchard (12), for the period prior to 1895, and by Richards (15) up to 1921.

### Views of McCoy and the Victorian Geological Survey.

Although Professor (afterwards Sir Frederick) McCoy never expressed his views in the form of a correlation table, yet it is possible from publications to infer them and those of the Geological Survey of which he was the palaeontologist, and to translate them into the local nomenclature established since his lifetime.

In 1861 McCoy (280, p. 168) referred the beds between Mount Martha and Mount Eliza [Balcombe Bay = type Balcombian] to the Upper Eocene, but five years later (281, p. 323) adopted for them the newly introduced term Oligocene, while he regarded the greater part of the Victorian Tertiaries as Lower Miocene. Subsequently he always combated the prevailing contemporary view of an Eocene age, remarking in 1894 (168, p. 48) that the Muddy Creek and Schnapper Point [Balcombe Bay] beds were "of newer date than any true Eocene Tertiary type, such as the London clay."

From papers published between 1874 and 1882 (282-288) one can set out McCoy's views on correlation as follows:—

*Oligocene:* Near Mount Martha [Balcombe Bay = type Balcombian]; near Mount Eliza [Grice's Creek]; Moolap, Ad. 14 [Curlewis; later, as Outer Geelong Harbour, Ad. 12, to Miocene]; Fyansford. As Oligocene or Upper Eocene: 2 miles NW. of Cape Otway. As Lower Oligocene: coast between Aire River and Castle Cove; Princetown, 3 miles W. of Gellibrand River. As Upper Oligocene: Shelford.

*Miocene:* Bird Rock Point, ¾ mile W. of Spring Creek [Torquay = type Janjukian, as Lower, Middle, and Upper Miocene]; Waurn Ponds; Corio Bay; Boggy Creek, near Sale; Mitchell River, Bairnsdale. As Middle Miocene: coast 1 mile W. of Sherbrook River. As Upper Miocene: Muddy Creek [upper beds]; Moorabool River, near Maude [upper beds].

*Pliocene:* By implication, Jemmy's Point, Gippsland Lakes [Kalimna = type Kalimnan]. As Lower Pliocene: Mordialloc [Beaumaris, upper beds = type Cheltenhamian]; Flemington [Royal Park, lower beds].

It will be seen that McCoy would have regarded the Balcombian as antecedent to the Janjukian, but that he included with the former the Cape Otway and Aire Coastal sections, which others have referred to the Janjukian. He would also have regarded the upper beds of Muddy Creek as pre-Kalimnan and the lower beds at Flemington as post-Barwonian, neither view being accepted by any subsequent author.

McCoy's views were essentially those of the Geological Survey of Victoria, as summarized in 1887 by Murray (9), who recognized three principal groups—Lower Tertiary (Oligocene), Middle Tertiary (Miocene), and Upper Tertiary (Pliocene), and given more fully by Pritchard (12, pp. 358-9).

### Views of Tate and Dennant.

In 1878, soon after his arrival in South Australia, Professor Tate (171) divided the marine beds at Aldinga into two series, later (47) called Eocene and Miocene, and those of the River Murray cliffs into three series, of which the upper was placed on the same horizon as Hallett's Cove and the upper Aldinga beds in South Australia and the Muddy Creek beds in Victoria. The lower Aldinga beds, though equivalent in part to the middle and lower Murray series, were considered on the whole inferior to them. These views were set out in tabular form (47, p. liii) in the following year.

In 1885 Tate (175), having restricted his upper Murravian series to the oyster beds, correlated instead the middle Murravian with the Muddy Creek beds, which in 1889 Dennant (83) showed to be divisible into two series. The lower, regarded as low in the Eocene, Dennant placed with the beds of Mornington [Balcombe Bay]; the upper, believed not older than Miocene, with those of Mordialloc [Beaumaris]. As next younger than these latter, and probably early Pliocene, Dennant regarded the Ostrea limestone of the upper part of the cliffs at Portland Bay and the Glenelg River.

In the following year he discussed further (84) supposedly still younger beds on the Glenelg River, originally described by him in 1887 (82), under the name of Bankivia beds, as Pleistocene. These constitute the type beds of the Werrikooian.

Meanwhile Tate (177) had announced the discovery, by borings in the Adelaide plains [type Adelaidean], of marine Pliocene in South Australia, and had discussed (178) the Tertiary stratigraphy of the Adelaide area.

Still later Dennant (85) correlated with the upper beds at Muddy Creek, as Miocene, the strata at Jemmy's Point [type Kalimnan], and with the Eocene those of the Mitchell River near Bairnsdale. These two deposits were subsequently described in greater detail by Dennant and Clark (90, 91).

During the period 1893-6 Tate and Dennant, in a series of papers (183-185), discussed in detail the correlation of the marine Tertiaries of Australia, a summary of which had been given by Tate (49). These authors referred all the marine deposits classed as Oligocene and as Miocene by the Geological Survey of

Victoria, to the Eocene, in which they noted, however, two faunal types. One, the Aldinga-facies, which probably indicates a relatively low position in the Eocene, is represented in the deeper beds of the Adelaide bores and in Victoria at Cape Otway. The other, best known at Muddy Creek, is conspicuous in most Victorian sections, such as the Gellibrand River, Camperdown, Shelford, and the Geelong district, including Western Beach [Corio Bay], Lower Moorabool [Batesford-Fyansford] and Curlewis-Belmont, as well as the Murray River and Mount Gambier district in South Australia; probably also Schnapper Point [type Balcombian] and Bairnsdale. As to Spring Creek [type Janjukian] and Table Cape (Tasmania), the authors reserved their opinion, but considered at Birregurra there is a mingling of the two faunas.

The views of Tate and Dennant may be condensed as follows:—

*Eocene:* In South Australia: Wilson Bluff to Head of Great Australian Bight; Point Turton, Edithburg, Surveyor's Point, etc., on Yorke Peninsula; lower beds in Adelaide bores and at Aldinga; Kingscote on Kangaroo I.; River Murray Plain; Mount Gambier District.

In Victoria: Muddy Creek (lower beds); Portland, Glenelg River, and Apsley; Warrnambool; Camperdown; Port Campbell, Sherbrook River, and Gellibrand; Aire River and Cape Otway; Spring Creek [type Janjukian]; Birregurra; Shelford; Maude (lower beds); Moorabool and Barwon Rivers, Geelong district; Schnapper Point [Balcombe Bay; type Balcombian]; Cheltenham [Beaumaris; type Cheltenhamian]; Mitchell River, Bairnsdale.

In Tasmania: Table Cape.

*Miocene:* In South Australia: River Murray Cliffs (oyster-beds or Upper Murravian series); Adelaide; Aldinga Bay and Hallett's Cove.

In Victoria: Portland and Glenelg River (Ostrea-limestone); Muddy Creek (upper beds); Jemmy's Point [type Kalimnan].

*Older Pliocene:* Marine sands beneath mammaliferous drift of Adelaide Plain [type Adelaidean], South Australia.

*Newer Pliocene:* Glenelg River at Limestone Creek, Victoria [type Werrikooian]. These were later regarded as Lower Pleistocene by Tate.

Subsequently Tate, in one of his last papers (181), modified his views, notably as regards the Spring Creek beds, as follows:—

*Post-Eocene (? Oligocene):* Beaumaris (Cheltenham), Murray Desert, Table Cape, and Spring Creek [type Janjukian].

*Upper Eocene:* Muddy Creek, Gippsland Rivers, River Murray, around Port Phillip [includes type Balcombian], Gellibrand River, and upper part of Lower Aldingian Series.

*Middle Eocene:* Cape Otway and middle section of Lower Aldingian.

*Lower Eocene:* Chalk of the Great Australian Bight, lower part of Lower Aldingian Series, and Croydon Bore.

It is noteworthy that, like McCoy, Tate would have placed the Balcombian below the Janjukian, thus reversing Hall and Pritchard's sequence, yet he agreed with the latter authors in placing the Cape Otway and part of the lower Aldinga beds (included in the Janjukian by Hall and Pritchard) below those of Muddy Creek and Balcombe Bay.

Finally, in 1903, Dennant and Kitson (275), in a faunal catalogue, utilized the following:—

*Eocene to Oligocene:*

*Group A* (including Lower and Middle Eocene of Tate): Aldinga, Adelaide Bore, etc., in S. Australia. Brown's Creek, Cape Otway, Aire Coast, etc., in Victoria.

*Group B.* (Upper Eocene of Tate): Murray River and Mt. Gambier in S. Australia. Glenelg River, Muddy Creek [lower beds], Gellibrand River, Camperdown, Birregurra, Shelford, Lower Moorabool [Fyansford, etc.], Corio Bay, Mornington [Balcombe Bay, type Balcombian], Flinders and Mitchell River, in Victoria. Tentatively included are the Victorian localities of Fishing [= Fisher's or Fischer's] Point on the Aire River, Waurn Ponds, and Maude.

*Group C* (Tate's post-Eocene, on which Dennant and Kitson express no opinion): Spring Creek [type Janjukian], Victoria. Table Cape, Tasmania.

*Group D* (provisionally Oligocene): Murray Desert in S. Australia. Keilor, South Yarra, Royal Park, and Beaumaris [type Cheltenhamian] in Victoria, the presence of two series at the two last mentioned localities being regarded as unestablished.

*Miocene:* Hallett's Cove, upper beds at Edithburg, Adelaide, Aldinga and Murray Cliffs in South Australia. Horsham; upper beds at Glenelg River, Muddy Creek, Shelford and Bairnsdale; Gippsland Lakes [Kalimna, type Kalimnan, etc.].

*Older Pliocene:* Dry Creek and Croydon Bores, near Adelaide, S. Australia [Adelaidean].

*Newer Pliocene:* Limestone Creek [type Werrikooian], Glenelg River; Moorabool Viaduct, Victoria.

## Views of Hall and Pritchard.

Tate's view as to the Eocene age of the Older Tertiary deposits was supported by Hall and Pritchard, who in 1895 (106) proposed their subdivision in Victoria, from above downwards, as follows:—

(1) *Clays of the Lower Muddy Creek Type.*—Muddy Creek, Gellibrand, Camperdown, Birregurra, Shelford, Murgheboluc, Southern Moorabool Valley (Fyansford, etc.), Belmont, Lake Connewarre (Campbell's Point), Curlewis, Corio Bay, Altona Bay (bore), Newport (shaft), Mornington [Balcombe Bay], Bairnsdale (Mitchell River).

(2) *Polyzoal Limestone of the Waurn Ponds Type.*—Waurn Ponds, Batesford, Maude [upper beds], Curlewis, Flinders, and perhaps at Airey's Inlet and Muddy Creek.

(3) *Clays and Limestones of the Spring Creek Type.*—Spring Creek, Maude [lower beds] and perhaps North Belmont.

This is substantially the same as that set out, as their joint views, by Pritchard (12), except that the clays and limestones of Curlewis and Belmont are there included under No. 2, as a sub-heading, and that North Belmont is omitted under No. 3, which is termed Lower Eocene and stated to be equivalent to the Lower Aldinga series in South Australia and probably to the Table Cape beds in Tasmania.

Within a year, in a rejoinder to Tate and Dennant's criticism (184), Hall and Pritchard withdrew (107) the Waurn Ponds limestone as a separate type, and associated it, as well as North Belmont, with the Spring Creek beds, but referred the limestones of Batesford and the upper beds at Maude to the Southern Moorabool Valley beds, grouped with the lower beds of Muddy Creek. They maintained, however, their view that the Spring Creek beds were older than those of Muddy Creek, a sequence which they sought to support both stratigraphically and statistically.

Still later these authors made an important innovation in the proposal (112) of a local nomenclature, in connection with which they offered the following correlation:—

*Werrikooian (Pliocene):* Limestone Creek [type], Victoria.

*Kalimnan (Miocene):* Jimmy's [Jemmy's] Point, Gippsland [type]; upper beds at Beaumaris, Shelford and Muddy Creek, Victoria; and of the Murray River cliffs and at Aldinga, S. Australia. Also the marine sands of the Dry Creek and Croydon Bores, S. Australia [Adelaidean].

*Balcombian (Eocene):* Balcombe's Bay [type] and Grice's Creek, Mornington; Bairnsdale; Altona Bay; Corio Bay; Curlewis; Belmont; Lake Connewarre; Southern Moorabool Valley [Batesford. Fyansford, etc.]; upper beds at Maude; lower beds at Shelford; Murghebolnc; Camperdown; Fishing Point, Aire River.

*Jan Jucian [afterwards Janjukian] (Eocene):* Spring Creek [type]; Waurn Ponds; lower beds at Maude; Cape Otway; and Aire Coast, Victoria. Lower beds at Aldinga, S. Australia. Table Cape, Tasmania.

The omission of the Muddy Creek lower beds is probably accidental, since these were always referred to the Balcombian by these authors. The inferior position of the Spring Creek beds is contrary to the view of McCoy, Tate and Dennant, though the two latter associated the Cape Otway and lower Aldinga beds at the base of their sequence.

## Views of Chapman and his Associates.

McCoy's views as to age and sequence were substantially those advocated for many years by Chapman, as palaeontologist to the National Museum, Melbourne, who in 1914 (22. 23, p. 50) set out his views, which may be thus summarized:—

*Oligocene (Balcombian):* Mornington (Balcombe's Bay and Grice's Creek); Muddy Creek (lower beds, at Clifton Bank); lower part of the bores at Sorrento, Altona Bay and Newport; all in Victoria.

*Miocene (Janjukian):* Spring Creek, Torquay; Bairnsdale; Flinders; middle beds of Sorrento bore; lower beds at Flemington [Royal Park];. Keilor; Corio Bay, Fyansford, Moorabool Valley and Batesford; Curlewis; Waurn Ponds; Birregurra; Camperdown; Grange Burn limestone; Mallee bores; in Victoria. Mount Gambier, Murray River, Murray desert, and lower beds at Aldinga, South Australia. Table Cape, Tasmania.

Of these he thought (22, p. 299) that the Corio Bay, Bairnsdale and Fyansford beds probably represented the basal part of the

Miocene, to the middle of which he referred those of Torquay and Batesford, which latter, however, had already been shown by Hall and Pritchard to underlie the Fyansford deposits.

> *Lower Pliocene* (*Kalimnan*): Gippsland Lakes (Jimmy's Point); upper beds of Shelford, Muddy Creek, and bores at Sorrento and Mallee; lower Glenelg River, Victoria. Adelaide and upper beds at Aldinga, S. Australia.
>
> *Upper Pliocene* (*Werrikooian*): Limestone Creek, Glenelg River; upper beds of Moorabool Viaduct and Sorrento bore, Victoria; and Murray basin, S. Australia.

In 1923 similar views were set out in greater detail by Chapman and Singleton (27), who regarded the bulk of the Tertiaries of South-eastern Australia as Janjukian and chiefly Lower Miocene; the Balcombian as Oligocene; the Kalimnan, with which were included the upper marine beds of Adelaide (later the type locality of the Adelaidean), as Lower Pliocene; and the Werrikooian as Upper Pliocene.

Thus in Chapman's view, maintained up to 1934, not only was the Balcombian antecedent to the Janjukian (270, p. 20) but coeval with the latter, of Miocene age, were the thick lignites of Yallourn (subsequently type Yallournian) and the earlier volcanic rocks known in Victoria as the "Older Basalt."

Two years previously, however, Sir Edgeworth David, in the explanatory notes to his new geological map of Australia (2, table I. and footnote p. 89), had on Chapman's authority placed the lowest beds of the Aldinga section, formerly correlated with the Janjukian, in the Oligocene and thus in the inferior position assigned to them by Tate more than half a century earlier.

Meanwhile the present author, largely as a result of studies, begun in collaboration with Chapman, of the Tertiary faunas of Fyansford and elsewhere in the Barwon River basin, had gradually become convinced that they were referable to the Balcombian, as had initially been claimed by Hall and Pritchard, and, by implication, McCoy, instead of to the Janjukian as had been maintained by Chapman since 1914. Since the author accepted the correlation of the lower Maude beds with the type Janjukian, and also the stratigraphic sequence between Maude and Fyansford first established by Hall and Pritchard, he was forced to accept also their view that Balcombian must succeed Janjukian, though he still agreed with Chapman and most of the workers of the past 25 years that both (comprised in the inclusive term Barwonian) were post-Eocene.

Consequently, in an outline of Victorian geology prepared late in 1934, the author (17) referred the Janjukian to the lowermost Miocene, the Balcombian to lower to middle Miocene, the Kalimnan to lower Pliocene, and the Werrikooian to the top of the Pliocene. The lignites of E. Victoria, under the term Yallournian, were classed as Oligocene, as was also the Older Basalt series.

Early in the following year Chapman, then Commonwealth Palaeontologist, and Crespin (26), gave a very full correlation of localities, but refrained from using the terms Balcombian and Janjukian, though they continued the use of Kalimnan and Werrikooian. Nevertheless the type localities of these two stages, Balcombe Bay and Torquay, above Spring Creek ledge, are both classed as Lower Miocene, while the beds below this ledge, which occurs in the lower part of the type Janjukian, are placed as Upper Oligocene, though qualified by the remark that the mollusca are typically lower Miocene and that "it may eventually be proved that the first 10 feet [from the base] of the Bird Rock Cliff section [i.e. type Janjukian] is a passage bed between the Upper Oligocene and Lower Miocene" (26. p. 121).

Thus it may be deduced that Chapman has largely reversed his views up to that date as to the sequence of these divisions of the Barwonian, since these authors now correlate the greater part of the type Janjukian with the type Balcombian, but consider the base of the former slightly antecedent to the Balcombe Bay beds, with which they now also group Fyansford and other disputed localities which Chapman had asserted to be post-Balcombian and to be referable to the Janjukian. They also regard Upper Oligocene and Lower Miocene as present in the lower Aldinga beds, S.A. It will be seen that Chapman and Crespin's view does not greatly differ from that of the present author, except as regards the supposed equivalence of the greater part of the Janjukian with the Balcombian, but that it does greatly differ from that previously expressed by Chapman and Singleton in 1923 and by the former (270, p. 20) as recently as 1934.

Still more recently the present author (44) has suggested that the Adelaidean horizon, referred by Hall, Pritchard, Chapman and Singleton to the Kalimnan, might be interpolated, as Middle Pliocene, between it and the Werrikooian, an intermediate position first assigned to these beds, though as Lower Pliocene, by Tate.

## Summary of the Correlation of the Marine Deposits.

### Eocene.

Paleocene to Middle Eocene horizons are as yet unknown in Australia, the earliest marine beds being those discovered in 1934 between Giralia and Bullara, near the head of Exmouth Gulf in North-west Australia. These are foraminiferal and bryozoan limestones, often with rolled quartz grains, forming a thin series (10 feet-30 feet?) overlying, apparently disconformably, the Upper Cretaceous Cardabia series which may be Campanian in its upper part (*sed vide infra*, p. 57).

The two occurrences at present known are at the northern end of the Giralia Range, a shallow anticlinal structure whose eastern limb has been eroded through the Tertiary beds into the underlying Cretaceous (73, 74, 156). Both localities are near the Giralia-Bullara road; one on the east flank of the Giralia anticline where the track to Bullara crosses the first low hills, the other in the bed of a creek at track crossing, nine miles from Bullara. At both the characteristic foraminiferal genus is *Discocyclina*, accompanied at the former by *Pellatispira* and *Asterocyclina*, at the latter by *Pellatispira* and *Nummulites*. These foraminiferal faunules have been referred by Chapman and Crespin (306) to the middle and upper parts of stage *b* of the East Indian sequence, which is approximately Upper Eocene. They thus represent a stage, as yet unknown in South-eastern Australia, which may conveniently be referred to as Giralian.

Friable *Discocyclina* limestones have been reported still more recently (78) from Red Bluff and Cape Cuvier, more than 100 miles to the S.S.W.

The discovery near Merlinleigh Homestead, 115 miles east of Cape Cuvier, of an internal mould in ferruginous sandstone described by Miller and Crespin (569) as *Aturia* cf. *ziczac* (Sowerby), suggests that the Eocene may have once extended over a hundred miles inland from the present coastline.

In South-west Australia soft calcareous shales from deep borings in King's Park and elsewhere near Perth, have recently been referred by Parr (338) to the Upper Eocene on the evidence of a very different foraminiferal faunule, which combines species identical with or similar to restricted Eocene forms in America, such as *Dentalina colei, Bolivinopsis eocenica,* and *Discorbis assulatus,* with a slight Oligocene element, including *Cyclammina incisa,* first described from the Lower Oligocene of New Zealand, and not uncommon in the Oligocene of Victoria.

## Oligocene.

Limestones in the Cape Range, south of North West Cape, first recorded by Chapman (301) as Oligocene, largely on the identification of *Lepidocyclina* (*Eulepidina*) *dilatata*, were subsequently regarded as younger by Crespin (78), who reported also the eulepidines *L. papuanensis* and *L. chapmani*. But according to Umbgrove (Leidsche Geologische Mededeelingen, Deel V., p. 69, 1931), *L. papuanensis* belongs to the horizon Tertiary *d* in the East Indies, being found in the Tempilan beds of East Borneo, and this horizon in the Cape Range is here referred to the Upper Oligocene.

In Victoria, *Lepidocyclina* first appears on a later horizon, regarded by Chapman and Crespin (26) as Lower Miocene, but underlying it are beds which they have referred to the Upper Oligocene, including the micaceous foraminiferal marls with *Cyclammina* and *Victoriella* (as well as the underlying oil-bearing glauconite bed) of the lower part of the deep borings of the East

Gippsland area, and similar beds in bores at Portland and in N.W. Victoria. As already noted, they also included as Upper Oligocene the base of the Janjukian at its type section, together with the Aire coastal sections in Victoria and the lower part of the lower Aldinga beds in South Australia.

All these are regarded by the author as referable either to the Janjukian, as basal Miocene or possibly the summit of the Oligocene, or to an as yet unnamed pre-Janjukian stage, probably to be regarded as high in the Oligocene, and with them may be placed part of the marine beds of the Torquay bore, at the type Janjukian locality.

Underlying them in turn are the so-called lignitic beds, which are carbonaceous sands and clays apparently chiefly of estuarine origin, at the base of the East Gippsland, Torquay, Dartmoor, and Mallee bores in Victoria, and underlying the marine lower Aldinga beds and elsewhere in South Australia. These are referred to the Oligocene by the author, and to the Lower Oligocene by Chapman and Crespin. South-west of Torquay they outcrop, as dark carbonaceous sands with *Cyclammina*, in cliff sections (102) east of Anglesea, whence they may be termed Anglesean.

## Miocene.

Chiefly referable to the earlier Miocene, but perhaps in part extending back into the Oligocene, is the main development, both in thickness and in geographic distribution, of marine Tertiary strata in Australia.

In the North West Division of Western Australia they are best developed in the North West Cape Range, on the eastern side of which are limestones 550 feet in thickness with abundant Lepidocyclinae (74). In addition to the eulepidine horizon above referred to the Upper Oligocene is one in which the eulepidines *Lepidocyclina murrayana* and *L. insulaenatalis* are associated with the nephrolepidines *L. angulosa*, *L. ferreroi*, and *L. verbeeki* and *Cycloclypeus* (78). This is Lower Miocene, to be correlated with the upper part of Tertiary *e* of the East Indies, and slightly older than the Batesfordian of Victoria. Overlying these are white foraminiferal limestones about 60 feet thick, apparently also Miocene, and still higher well-bedded white limestones 100 feet thick, of uncertain age (74).

Foraminiferal and bryozoan limestones also occur in the Rough, Giralia, and Waroora Ranges, and extend southwards to Salt Lake, north of Shark Bay, a total distance of nearly 160 miles.

From the Cape Range and Rough Range areas, and from borings at Carnarvon, Miss Crespin (78) has referred to the Middle Miocene foraminiferal limestones with, in addition to nephrolepidines, *Marginopora vertebralis*, *Flosculinella bontangensis*, and the widespread *Trillina howchini*, first described (343) from the lower Muddy Creek beds (Balcombian) of Victoria. These suggest a correlation with Tertiary *f* of the East Indies.

Still further south, at Champion Bay near Geraldton, marine Tertiary rocks of varied lithological types (7) form a coastal strip of which little is known.

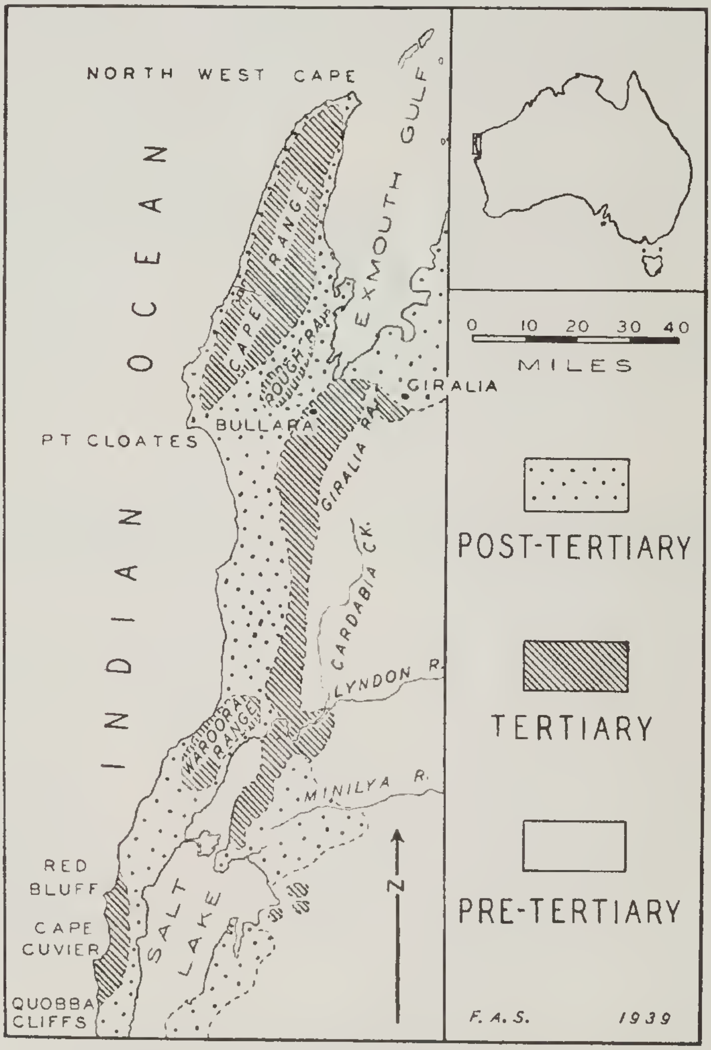



Fig. 1.—Tertiary rocks of North West Australia. Modified from Raggatt, 1936 (156, pl. 3).

In South Western Australia the Plantagenet beds (7, 8, 133) are developed along the south coast near Albany, and from Cape Riche to the Phillips River. They consist chiefly of siltstones with a maximum thickness of 300 feet, resting upon granite, and contain siliceous sponges and a small molluscan faunule (66, 271) with relations to the Janjukian of S.E. Australia. About 250 miles N.E. of Cape Riche, small exposures occur 120 miles inland near Norseman (8, 97), resting on pre-Cambrian rocks at 900 feet above sea level. They are mostly limestones with poorly preserved mollusca and bryozoa, except at Princess Royal, where silicisponge spicules (347) occur in a siliceous rock.

On the southern coastline Tertiary limestones are believed to extend from Israelite Bay, past Point Culver and Twilight Cove, to Wilson's Bluff near Eucla, where they pass into South Australia and reach as far as the Head of the Great Australian Bight, a total distance of about 500 miles. Little is known of this great limestone plateau, extending inland beneath the Nullarbor Plains and believed to cover an area approximating to that of Victoria. Over most of this western part of the Great Australian Bight the high cliffs show apparently horizontal strata, chiefly the Eucla limestone (7).

At Wilson's Bluff (172) this comprises from below 188 feet of chalky white bryozoan limestone with two layers of flints and with echinoids, including *Salenia tertiaria,* becoming harder in its upper part, rich in brachiopoda, chiefly "*Magellania*" *insolita*: 12 feet of yellow bryozoan limestone with *Cellepora*; and 50 feet of grey to brown crystalline limestone with molluscan casts. Tate correlated the first two with the lower Aldinga beds of South Australia, and the third with the upper Aldinga beds, which are usually regarded as Kalimnan. The author believes the crystalline limestones may, however, correspond with those of Ooldea (58), near the north-eastern limit in South Australia of the Nullarbor Plains, which are certainly pre-Kalimnan. In deep borings inland in Western Australia the Eucla limestone is reported to attain a thickness of 500 to 900 feet, when its lower portion might well range down into the Oligocene; it is, however, possible that these bores may have entered Cretaceous rocks.

In South Australia bryozoan limestones are found on Yorke Peninsula (52, 121, 176, 186) as well as on Kangaroo Island (116, 118, 174) and on the east side of Gulf St. Vincent (69, 122, 185) from Gawler southward to near Sellick's Hill. Fossiliferous sands and clays occur in deep borings near Adelaide (180), and outcrop in the lower part of the cliffs at Aldinga Bay (122, 185). These, with the Cape Otway clays (110, 184) in Victoria, are regarded by the author (44) as either Janjukian or less probably referable to the stage which precedes it.

In the south-east of South Australia are the limestones and calcareous sandstones exposed along the River Murray cliffs (169, 175), of which the middle beds are doubtfully Balcombian, and cut by borings in the Murray Plains (68, 123, 182), while bryozoan limestones outcrop at Mount Gambier (190), whence they pass into Victoria.

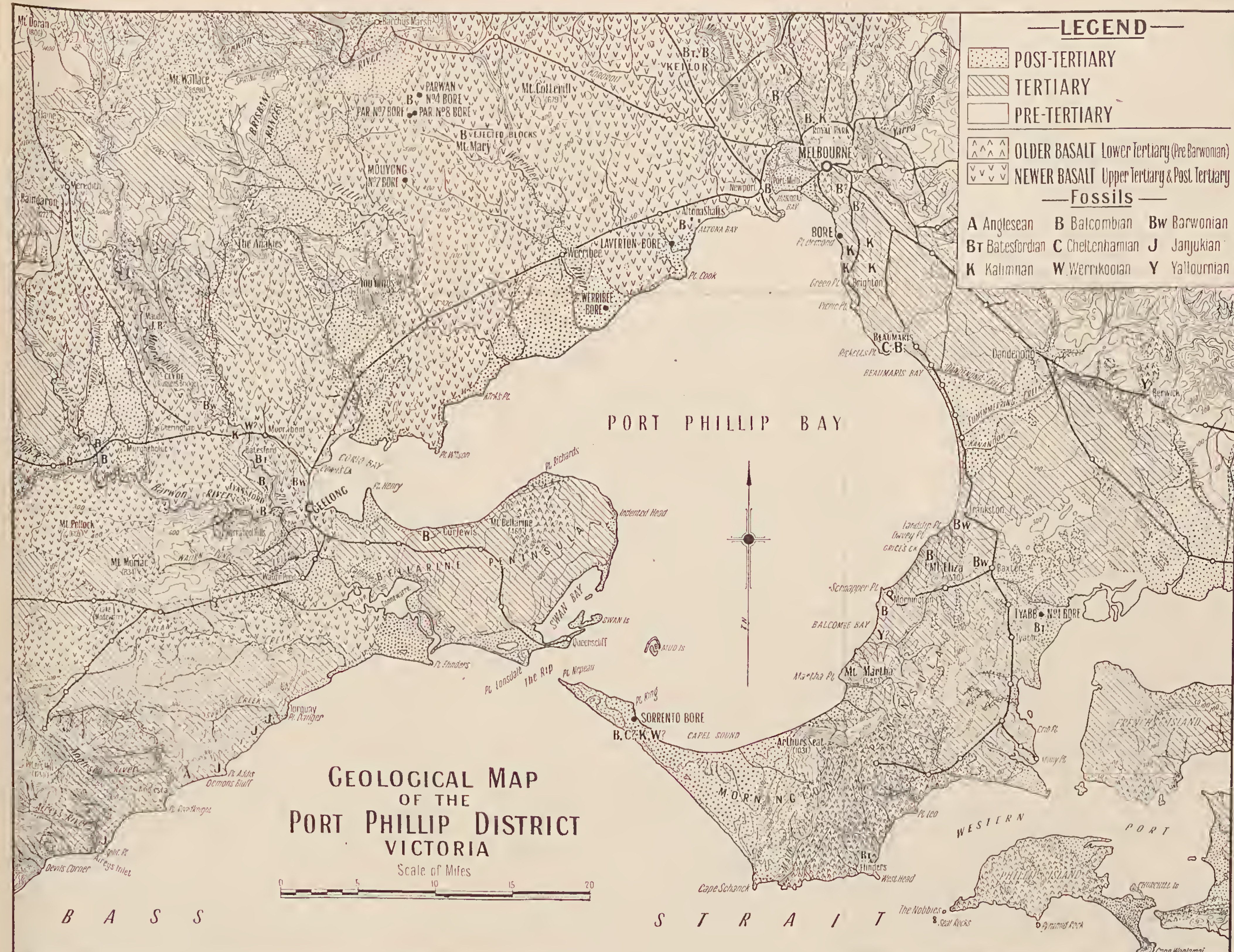
Portions of the ancient "Murray Gulf" extend into New South Wales, where Janjukian beds were cut at 647 feet in the Arumpo bore (94) and at 420 feet in the South Ita bore (44, 134), the latter 65 miles south of Broken Hill, and into Victoria, known by numerous borings in the Mallee and Wimmera districts. In Victoria, in addition to this north-western area, the principal regions of deposition are in the south west, more or less continuous beneath a basalt cover with that of South Central Victoria, and in East Gippsland in the south-east of the State.

Two main stages are recognizable in Victoria, which together constitute the *Barwonian System*, chiefly Miocene but perhaps extending back into the Upper Oligocene.

The earlier, in the author's view, is the *Janjukian stage* or group, typified by the lower beds (shelly clays and glauconitic marls) and upper beds (bryozoan limestones) of Bird Rock cliffs near Torquay (107, 183, 184). Near the base of the section, which is about 180 feet in thickness, are beds with *Spirulirostra curta*, closely related to the Miocene genotype *S. bellardi*, and a boring has proved a further 170 feet, giving a total thickness of about 350 feet. In Victoria the lower Maude beds (23, 106, 184), and in Tasmania the Table Cape beds (6, 131, 150, 166, 185), with *Prosqualodon davidis* (595-597), are here placed in the Janjukian, as Lower Miocene or even Oligo-Miocene, as are less certainly the Cape Otway and Aire Coast sections (50, 110, 184). Less than 1 per cent. of the Janjukian molluscan fauna of about 250 species is still living.

The later or *Balcombian stage* is based on 35 feet of shelly marls, with an equal thickness proved by boring, at Balcombe Bay (111, 114, 135) near Mornington, Port Phillip, with similar beds at Grice's Creek (111, 135) nearer Frankston, and on the Mitchell River (91), Gippsland; in depth at Altona (23, 72, 108, 187) on Port Phillip and north-westerly towards Parwan (38); Murgheboluc (113), Fyansford (104), etc., in the Barwon River Basin; Gellibrand River (183); and lower beds at Muddy Creek (23, 83, 183) near Hamilton in Western Victoria. Here the marls contain over 400 species of mollusca, of which *Aturia australis*, closely related to the European *A. aturi*, and a new species of *Spirulirostra* are noteworthy, as is the pelagic miliolid *Trillina howchini*, known in the Miocene of Java (Tertiary *e*), Borneo (Tertiary *e* and *f*?), Phillipines, Pemba I. near Zanzibar, Irak, and I. of Paxos in Greece (273). They are rich in *Amphistegina lessonii* and the pteropod *Vaginella eligmostoma*, and are shown by a boring to be underlain by limestones with Lepidocyclinae, which outcrop nearby on Grange Burn.

The Batesford limestone (104, 299) with similar Lepidocyclinae, the commonest of which has been regarded as *Lepidocyclina tournoueri* (299), for which the term Batesfordian was




MAP 2.

Geological Map of the Port Phillip district, Victoria. Modified from map in A.N.Z.A.A.S. Handbook for Victoria, 1935.

proposed (27), is similarly overlain by the Fyansford clay, here referred to the Balcombian.

The Batesfordian is thus either a late Lower or early Middle Miocene stage, also represented at Keilor (77), Flinders (27, footnote p. 989; 137), and in the East Gippsland bores (25), (characterized by nephrolepidines and a trybliolepidine but no eulepidines, and probably to be correlated with part of the East Indian Tertiary *f*), which immediately precedes the Balcombian (the view here adopted), or it may ultimately prove to be merely a calcareous facies of the latter. In either case a Middle Miocene age is probable for the Balcombian, of which a littoral facies may be represented by the limestones of the upper beds at Maude (106) and the ironstones of Keilor (77, 108) and the lower beds at Royal Park (70, 108, 158) near Melbourne.

The Balcombian mollusca of the type locality total about 300 species, of which living species are not more than 1 per cent.

To some part of Barwonian time belong the bryozoan limestones of King (55, 80) and Flinders Islands (132) in Bass Straits and near Cape Grim (6, 10) and Marrawah (10) in North-West Tasmania.

The Upper Miocene may be represented in many cases by the stratigraphic break, marked by a "nodule bed" or rarely a slight angular unconformity, at the base of the Kalimnan (Lower Pliocene) where it rests on Barwonian deposits. Perhaps Upper Miocene in part are white limestones on the western side of the North West Cape Range in Western Australia (74), and the beds immediately underlying the Kalimnan of the Sorrento (63) and East Gippsland (25) bores in Victoria.

A probably Upper Miocene stage, which may be distinguished as Cheltenhamian, can be based on the marine ferruginous sands, overlying Balcombian clays just below low-water mark, of the cliffs at Beaumaris, near Cheltenham, Port Phillip (71, 108). These upper beds have usually been referred to the Kalimnan (Lower Pliocene), largely on the mollusca, but an Upper Miocene age is suggested by teeth of the cetacean *Parasqualodon* and by the presence of *Aturia*, a cephalopod elsewhere not surviving the Miocene.

## Pliocene.

In North Western Australia this is doubtfully present in the limestones above-mentioned in the western side of the Cape Range, which have been provisionally termed Mio-Pliocene (74).

In South-Eastern Australia three stages have been proposed, and a fourth probably remains to be recognized.

The *Kalimnan stage* (Lower Pliocene) is based on the sandy clays of Kalimna (85, 90) in East Gippsland, which, with an extension in bores, are about 150 feet thick. To it are referred sands and marls of the upper part of the borings of East Gippsland (25), Sorrento (63), the Mallee (57) and Wimmera districts, of outcrops at Muddy Creek (upper beds) (83, 272), in Victoria; and more doubtfully the upper beds of the Murray Cliffs (175) and of Aldinga (185) in South Australia. They are neritic deposits of whose molluscan species, totalling about 110 at Kalimna and more than 150 at Muddy Creek, perhaps 10 per cent. are still living.

The *Adelaidean stage,* known only in borings beneath the Adelaide Plains, South Australia, is based on the fossiliferous marine grey to white sands, about 160 feet thick, cut at about 300 feet below sea level in the bores at Dry Creek (177), the Abattoirs (126), and elsewhere (124, 125). They are shallow water deposits whose molluscan fauna, with perhaps 20-25 per cent. of living species in a total of about 200, shows more relationship with the Kalimnan, with which it has often been correlated, than with the Werrikooian. Nevertheless, it is probably post-Kalimnan, a conclusion supported by the foraminiferal faunule, and it may be tentatively regarded as Middle Pliocene (44).

The *Werrikooian stage* is typified by shallow water shell beds, on the Glenelg River near Limestone Creek, in Western Victoria (82, 84, 159), of whose molluscan fauna of about 200 species about 95 per cent. are still living, and may be placed at the top of the Pliocene, with a gap representing an as yet undiscovered stage or stages between it and the Adelaidean. This basal shell bed is not more than a foot in thickness, and is conformably overlain (159) by the Ostrea Limestone (84, 183), a series of 30 to 50 feet of flaggy sandy limestone, often false-bedded, widespread in south-west Victoria from Portland to the South Australian border, and notable for the first appearance of *Pecten* (*Notovola*).

Doubtfully correlated with the Werrikooian are beds at Moorabool Viaduct (144) and in the Sorrento (63) and Mallee (57) bores, in Victoria; in a bore at Wingaroo (10, 26, 44, 526), Flinders Island, Bass Straits; and in the Tintinara bore in South Australia (57, 68, 123, 179); but demarcation from marine Pleistocene is often difficult.

Near Moruya on the south coast of New South Wales are ferruginous grits with poorly preserved shell moulds for which the author has with some doubt suggested an Upper Cainozoic age (21, p. 337; 653, p. 41).

## Definition and Discussion of Stage Names.

The following system and stage names have been proposed, or are herein suggested, for subdivisions of the Australian marine Tertiary strata:—Adelaidean, Aldingan, Anglesean, Balcombian, Barwonian, Batesfordian, Cheltenhamian, Gambierian, Giralian,


FIG. 2.—Geological map of Adelaide district, South Australia, with sites of bores cutting Adelaidean beds. Contours from Adelaide sheet, Military Survey of Australia, 1915.

Hamiltonian, Janjukian, Kalimnan, Murravian, Werrikooian, to which may be added Eyrian and Yallournian, proposed for non-marine deposits.

### Adelaidean Stage.

Proposed by Howchin (4, p. 423) in 1928 for beds which in South Australia "are only known by borings, and as these are situated within short distances of Adelaide, it is proposed to distinguish them as the Adelaidean Upper Pliocene . . . . The presence of this marine bed has been proved by borings at Croydon, Dry Creek, the Abattoirs, Salisbury, and Smithfield; also on the coastal plains to the north of Adelaide, at St. Kilda, north of the Outer Harbour, and at Kidman's Bore, 3 miles to the northward of the last-named bore. The bed is richly fossiliferous."

The best known of these borings, palaeontologically, are the Dry Creek bore, 5 miles north of Adelaide, and the Metropolitan Abattoirs bore, about 1½ mile to the east of Dry Creek. For the Dry Creek bore, from the surface at 14 feet above sea level, Tate (177, p. 172) gives the following sequence, the present writer's comments being added in brackets:—

0–120 feet. Clays. Pliocene or Mammaliferous Drift. [Recent to Pleistocene.]

120–320 feet. Sands. Not examined by Tate. [? Pleistocene.]

320–410 feet (bottom of bore). Fossiliferous sands. Older Pliocene. [Adelaidean].

For the Abattoirs bore, commencing at about 100 feet above sea level, the sequence described by Howchin and Parr (126, p. 289) is as follows:—

0–341 feet. Alluvial sand and gravel. Recent to Pleistocene.

341–500 feet. Fossiliferous marine sands. Upper Pliocene. [Adelaidean.]

500–820 feet (bottom of bore). Fossiliferous clays and calcareous sandstones. Miocene. [Barwonian.]

While similar beds have been reported by Tate (180) in the Croydon bore, by Howchin (124, 125) in the Brooklyn Park, Glanville and Cowandilla bores, and by Mrs. Ludbrook (140) in the Hindmarsh bore, all in the vicinity of Adelaide, the most suitable type sections, since unfortunately bore sections are all that are available, are those given by the two borings first mentioned.

*The Adelaidean may be defined as the interval of time represented by the deposition of the fossiliferous marine sands cut at 320 to 410 feet (306 to 396 feet below sea level) in the Dry Creek bore and at 341-500 feet (about 241-400 feet below sea level) in the Abattoirs bore, as well as those represented therein by non-deposition or erosion.*

In the Dry Creek bore the foraminifera were determined by Howchin (in Tate, 177, p. 177) and the mollusca by Tate (177, pp. 174-177), while for the Abattoirs bore the foraminifera have been exhaustively treated by Howchin and Parr (126), the

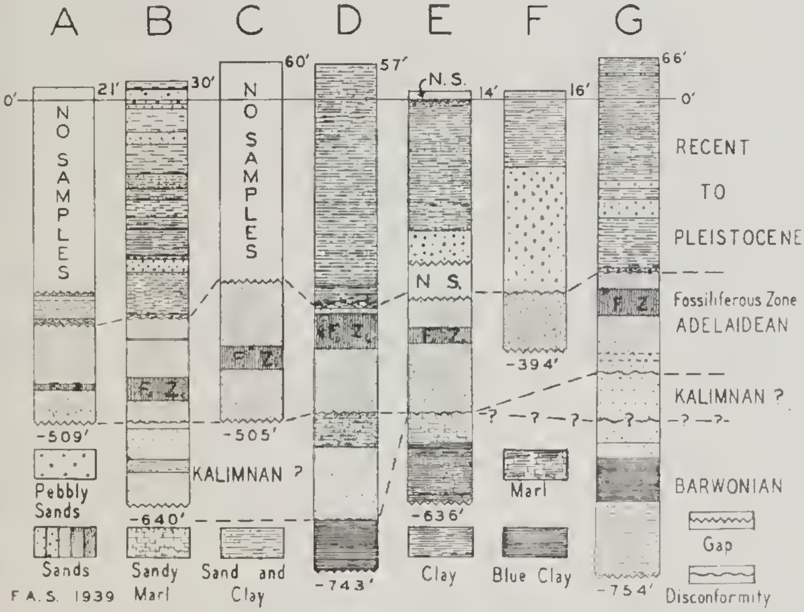



FIG. 3.—Comparative sections of Adelaidean beds near Adelaide. A. Brooklyn Park bore (124), B. Cowandilla bore (125), C. Hindmarsh bore (140), D. Croydon bore (178), E. Glanville bore (124), F. Dry Creek bore (177), G. Abattoirs bore (126).

bryozoa by Stach (431), and the pelecypods listed by N. H Woods (549, pp. 150-151). From these and other sources, a list of the characteristic fossils, in which the nomenclature, but not the identifications, of the mollusca has been revised, appears to be:—

Foraminifera: *Flintina triquetra* Brady.

Pelecypoda: *Glycymeris convexa* (Tate), *Ostrea sinuata* Lamarck, *Chlamys asperrimus antiaustralis* (Tate), *Codokia nuciformis* (Tate), *Miltha* (*Milthoidea*) *grandis* (N. H. Woods), *Lepton trigonale* Tate, *Chioneryx cardioides* (Lamarck), *Electromactra howchiniana* (Tate).

Gasteropoda: *Turritella* (*Ctenocolpus*) *trilix* Cotton and Woods, *Tylospira marwicki* (Finlay), *Neodiastoma provisi* (Tate), *Polinices balteatella* (Tate), *Cymatiella sexcostata* (Tate).

### Aldingan Stage.

Though the introduction of this name has been attributed to Tate by Chapman (57, p. 409) and by Chapman and Singleton (27, p. 985), that author at the reference cited (47, p. liii) uses only the terms Lower Aldinga Series and Upper Aldinga Series, in a correlation table of South Australian Tertiary strata. In one of his last papers, Tate (181, p. 107) in a Succession Table, again referred to the Lower Aldingian Series, which he subdivided under Lower, Middle, and Upper Eocene, the Middle Eocene including the " middle section of Lower Aldingian." It is clear from the context, however, that Tate used the term Lower Aldingian not as a stage name but only as a convenient method of referring to the lower beds at Aldinga, which he had originally described still earlier (171, p. 121).

The first usage as a stage name, in the amended form Aldingan, is therefore that of Hall and Pritchard (112, p. 79), who observed—" In the cliff sections, as described by Messrs. Tate and Dennant, ' Miocene ' overlies ' Eocene,' and the term Aldingian as used by them includes both sets of strata. If it be confined to the lower series only, it might perhaps be employed, though it violates the principle that a name should not be given where two distinct series are in contact. As we differ from the views of Messrs. Tate and Dennant on the question as to its equivalence or otherwise with the Spring Creek series, a type name may be thought desirable, though our own views are opposed to its use."

This correlation by Hall and Pritchard of the lower beds of Aldinga with the beds of Spring Creek (type locality of the Janjukian stage) was accepted by Chapman (23, pp. 50, 51; 57, p. 409) and by Chapman and Singleton (27, p. 986), though Tate (181, p. 107) had placed the Spring Creek beds on a later, " post-Eocene," horizon. Apparently Chapman and Crespin (26, p. 125) would place part of the lower beds at Aldinga on a slightly earlier horizon than those of Torquay (i.e., Spring Creek), and the writer has also considered this possibility (44).

If the term Aldingan be used for a stage it seems necessary that it should be confined in meaning to the Lower Aldinga Beds, which was, in fact, the restricted sense employed by Tate and Dennant (185, p. 141) when referring to the " Aldingian fauna."

As it has been used in two senses, as Hall and Pritchard, the introducers of the term, were opposed to its use, and as doubt exists as to its equivalence or otherwise with the Janjukian, it seems wiser to reject, at the present time, the Aldingan as a stage name.

### Anglesean Stage.

Here proposed for the black sandstone and sandy clays of the coastal cliffs extending from near the mouth of the Anglesea River east-north-easterly for about 2 miles towards Point Addis, in the Parish of Jan Juc, Victoria. At Demon's Bluff, near the centre of the section, the cliffs are over 250 feet in height, but are much scarred by landslips, and the relations of the beds are more clearly seen towards the Anglesea end.

On the axis of a gentle anticline, about a third of a mile north-east of the mouth of Anglesea River and half a mile east of the Anglesea bridge, a nearly vertical cliff section shows 41 feet of black sandstone overlain by 47 feet of white sands. The junction between them, at a spot 150 yards to the south-west, dips at 4½ degrees to the north-west. The dark-coloured somewhat carbonaceous sandstone commonly shows lighter coloured branching markings which are presumably algal, while locally the foraminiferal genus *Cyclammina* is abundant and, with the tooth of *Odontaspis contortidens* Agassiz recorded by Hall (102, p. 47), attests the marine origin of these poorly fossiliferous beds. The absence of a rich shelly fauna renders the locality by no means ideal as a type section, but nearly all other occurrences of beds correlable with the Anglesean, as in the East Gippsland, Mallee, and Dartmoor areas, are known only from borings and are thus unsuitable for selection.

The upward limit of the Anglesean is given by the overlying unfossiliferous white sands, but its downward extent, in the absence of borings, remains uncertain.

*The Anglesean may be defined as the interval of time represented by the deposition of the dark-coloured sands with* Cyclammina *of the cliff sections between Anglesea and Point Addis, as well as those represented therein by non-deposition or erosion.*

### Balcombian Stage.

This was introduced in 1902 by Hall and Pritchard (112, p. 78) as follows: "*Balcombian.* The clays and limestones of Balcombe's Bay contain another distinct fauna. The beds are sometimes spoken of as at Mornington, but the locality we give is more exact."

At the type locality, which is a coastal section on the eastern shores of Port Phillip, Victoria, immediately to the north of the old cement works near the northern end of Balcombe Bay, and about a mile and a half south of Mornington, the fossiliferous clays or marls, with interbedded concretionary hard limestone bands, have been described by Hall and Pritchard (111, p. 39).

The richly fossiliferous marls are exposed chiefly between tide marks, but fossils become scarcer and more fragile in the cliff section, in which the marls have a thickness of about 35 feet. They are overlain by ferruginous sands and grits, with which the junction is sharp but even. Boring has shown the calcareous

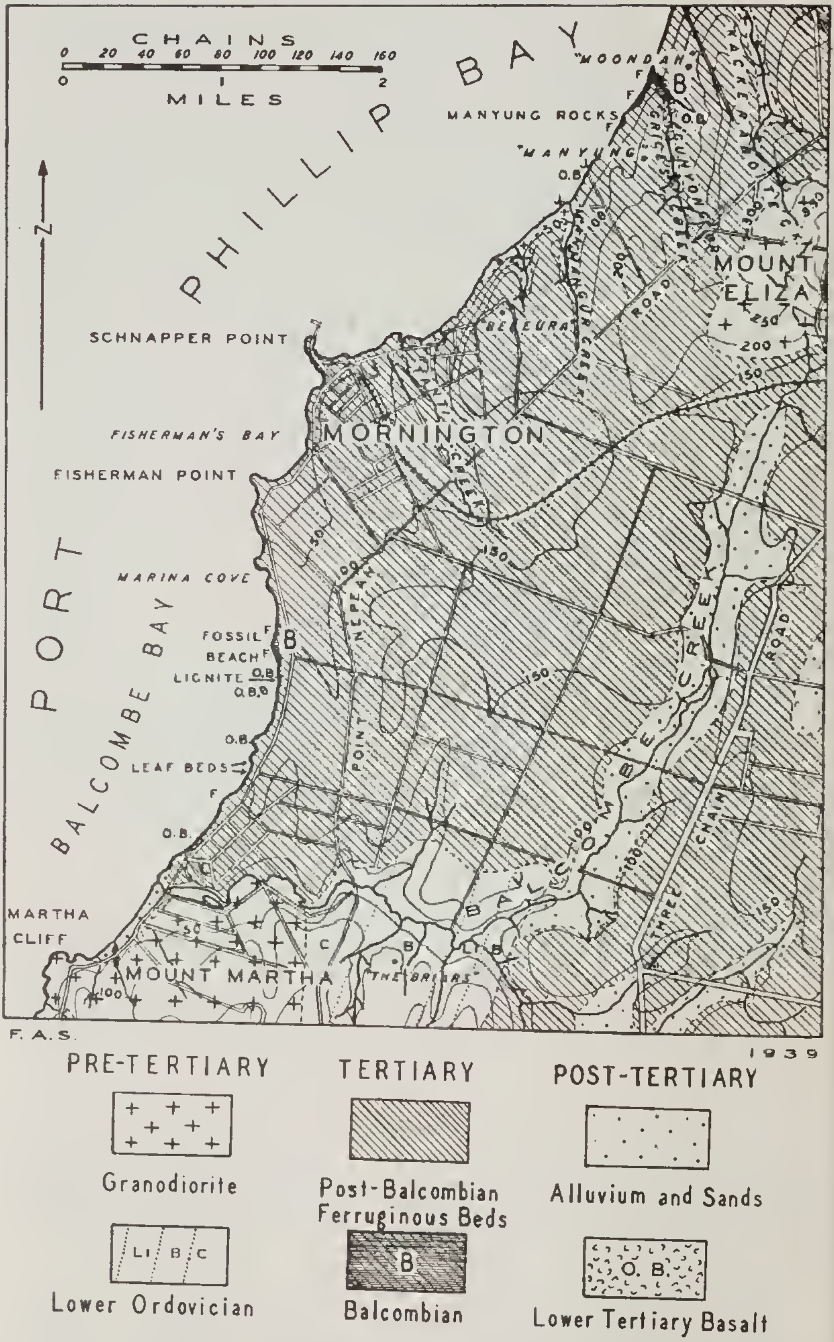



FIG. 4.—Geological map of Mornington district, Victoria. Modified from Kitson, 1900 (135), and unpublished mapping by R. A. Keble. Contours from Cranbourne sheet, Military Survey of Australia, 1912. J. Jurassic, F. Balcombian fossils.

marl to persist for 35 feet, and to be succeeded in depth by sandy clays, sands, and ligneous clays, and this apparently non-marine series is in turn underlain by basalt.

It is clear that from the original description the ferruginous series, though subsequently referred to the Balcombian by Pritchard (155, p. 937), must be excluded from the definition of the stage, though it is reasonable to include the extension in depth of the calcareous marl proved by the boring, Bore No. 6, Parish of Mooroodue (36, p. 30).

The cliff section (k-p) beach floor (h-j), and bore (a-g) give a sequence as follows, totalling 197 feet.

(*p*) 5 feet mottled clay.
(*o*) 5 feet ironstone.
(*n*) 4 feet ferruginous sandstone.
(*m*) 2 feet ferruginous grit.
(*l*) 10 feet ferruginous fine sandstone.
(*k*) 35 feet grey clays with selenite crystals in upper part.
(*j*) 1 foot septarian limestone nodules.
(*i*) 3 inches grey shelly clays.
(*h*) 1 foot grey clays with discoloured markings of seaweeds (?).
(*g*) 35 feet calcareous marl.
(*f*) 17 feet sandy clay.
(*e*) 24 feet sand.
(*d*) 2 feet ligneous clay.
(*c*) 4 feet coarse sand.
(*b*) 33 feet ligneous clay.
(*a*) 19 feet hard basalt.

Depth bored 134 feet.

Beds (b)-(f) constitute 80 feet of apparently non-marine strata, perhaps to be referred to the Yallourn series; beds (g)-(k) a fossiliferous marine series totalling 72 feet, in which most Balcombian fossils come from the richest bed (i), though fossils also occur above and below; and beds (l)-(p) belong to a ferruginous series, here 26 feet thick, which is widespread on the Mornington Peninsula.

*The Balcombian may be defined as the interval of time represented by the deposition of the grey marls and concretionary limestone bands constituting beds (g)-(k) in the above sequence at Balcombe Bay, as well as those represented therein by non-deposition or erosion.*

At the type locality the foraminifera have been dealt with by Chapman and his colleagues (298, 307, 310) in a monograph of the Balcombian Foraminifera of Port Phillip; the bryozoa were listed by Maplestone (423); the mollusca by Hall and Pritchard (111), and the latter and other groups by Dennant and Kitson (275); in the last three cases under the name Mornington, which refers to this section, as do " Schnapper Point," " Mount Martha," " between Mount Eliza and Mount Martha," and even " Hobson's Bay," of the earlier authors.

Characteristic mollusca include:—

Pelecypoda: *Limopsis morningtonensis* Pritchard.

Gasteropoda: "*Cerithium*" *apheles* T. Woods, *Umbilia eximia maccoyi* Schilder, *Austrotriton textilis* (Tate), *Chicoreus lophoessus* (Tate), *Dennantia ino* (T. Woods), *Volutospina antiscalaris* (McCoy), *Bathytoma rhomboidalis* (T. Woods), *Conus ligatus* Tate.

Pteropoda: *Vaginella eligmostoma* Tate.

Cephalopoda: *Nautilus balcombensis* Chapman.

Less common but apparently restricted species include:—

Pelecypoda: "*Chlamys*" *dichotomalis* (Tate), *Eucrassatella dennanti* (Tate).

Gasteropoda: *Turritella* (*Colpospira*) *platyspira* T. Woods, *Gigantocypraea gigas* (McCoy), *Solutofusus carinatus* Pritchard, *Pterospira hannafordi* (McCoy).

## Barwonian System.

In 1904 Hall and Pritchard (113, pp. 297-8) proposed this name, as a Barwonian Series, in these words: "In the paper in which we proposed the names Balcombian and Janjukian, we indicated the existence of certain beds which undoubtedly belonged to the older series comprised under these two names, which are clearly distinct from the younger Kalimnan, but which from the smallness of the collections available, we did not care to refer definitely to either Balcombian or Janjukian. In other words, the palaeontological differences between Balcombian and Janjukian series, though of importance, are not nearly so marked as between them and the Kalimnan. On these grounds we think it advisable that a name should be given which will comprise both Balcombian and Janjukian. The former series is extensively developed in the Barwon basin, and the latter at its typical exposure at Spring Creek, south of Geelong, is not far from the borders of the same basin, so that the name Barwonian is suggested."

The name is thus given to cover both Balcombian and Janjukian, and is *not* defined in terms of any type locality within the Barwon basin, in which the beds are, indeed, referred by these authors to the Balcombian. Chapman (57, p. 409) was therefore mistaken in believing the Barwonian to be "typified in the series from Red Hill, Shelford, through Inverleigh, Murgheboluc, down the Barwon valley to Fyansford," an error which had previously led him (56, p. 371) to discard the term Barwonian on the grounds that its members were included in the term Janjukian, to which he had referred (see Chapman and Singleton, 27, p. 986) the Tertiaries of the Barwon basin, instead of to the Balcombian as had done Hall and Pritchard.

*The Barwonian may be defined as the interval of time represented by the Janjukian and Balcombian as herein defined, as well as such as may intervene between them.*

### Batesfordian Stage.

The first use of the term Batesfordian was in 1914 by Chapman, who stated (23, p. 49), in reference to the white polyzoal limestone in bore No. 11 of the Victorian Mallee district—"The fauna altogether showed a strong Aldingan and Batesfordian aspect; both Aldinga (lower beds) and the Batesford Limestone being of Janjukian age." Apparently Chapman had no intention of using the term as a stage name, for it is not included in the list of subdivisions of the Cainozoic beds given by him in his account of the Cainozoic Geology of the Mallee Bores (57, pp. 409-411).

Accordingly, the first formal proposition of the Batesfordian stage was by Chapman and Singleton (27, p. 986) in 1925, as follows:—"*Batesfordian.*—Typified by the foraminiferal and polyzoal limestones of the quarries on the Moorabool River near Batesford, in the Geelong district, Victoria. These have been referred to by one of us (F.C.) to the Janjukian, and by Hall and Pritchard to the Balcombian." Later in the same paper (27, p. 990), it is stated that "Another calcareous facies of the Janjukian, characterized by the abundance of *Lepidocyclinae*, is the Batesfordian, to which are referred the foraminiferal and polyzoal limestones of Batesford, near Geelong, the junction of Grange Burn and Muddy Creek, near Hamilton, Violet Creek (in the same district), Green Gully, near Keilor, and Cape Schanck and Flinders, to the south of Port Phillip. These Batesfordian localities have all been relegated to the Balcombian by Hall and Pritchard."

The writer has already indicated his belief (*supra*, p. 19) that the Batesfordian is a stage immediately antecedent to the Balcombian.

At the time of proposition of the name there were two limestone quarries on the Moorabool River, a little more than a mile south-east of Batesford. One, on the left bank of the river, is known as the Upper Quarry, from which was formerly obtained a building stone termed "Moorabool Stone," a brownish dense limestone consisting largely of Lepidocyclinae. Hall and Pritchard (104, p. 11) gave the hill section at this locality, from above downwards, as follows:—

| | |
|---|---|
| "Basalt .. .. .. .. .. .. | 75 feet. |
| Incoherent sandy material, with calcareous concretions .. | 50 feet. |
| Yellow clay, with calcareous concretions .. .. | 5 feet. |
| Polyzoal limestone .. .. .. .. .. | 20 feet. |
| Orbitoides [*recte* Lepidocyclina] limestone .. .. | 20 feet. |
| Total: | 175 feet." |

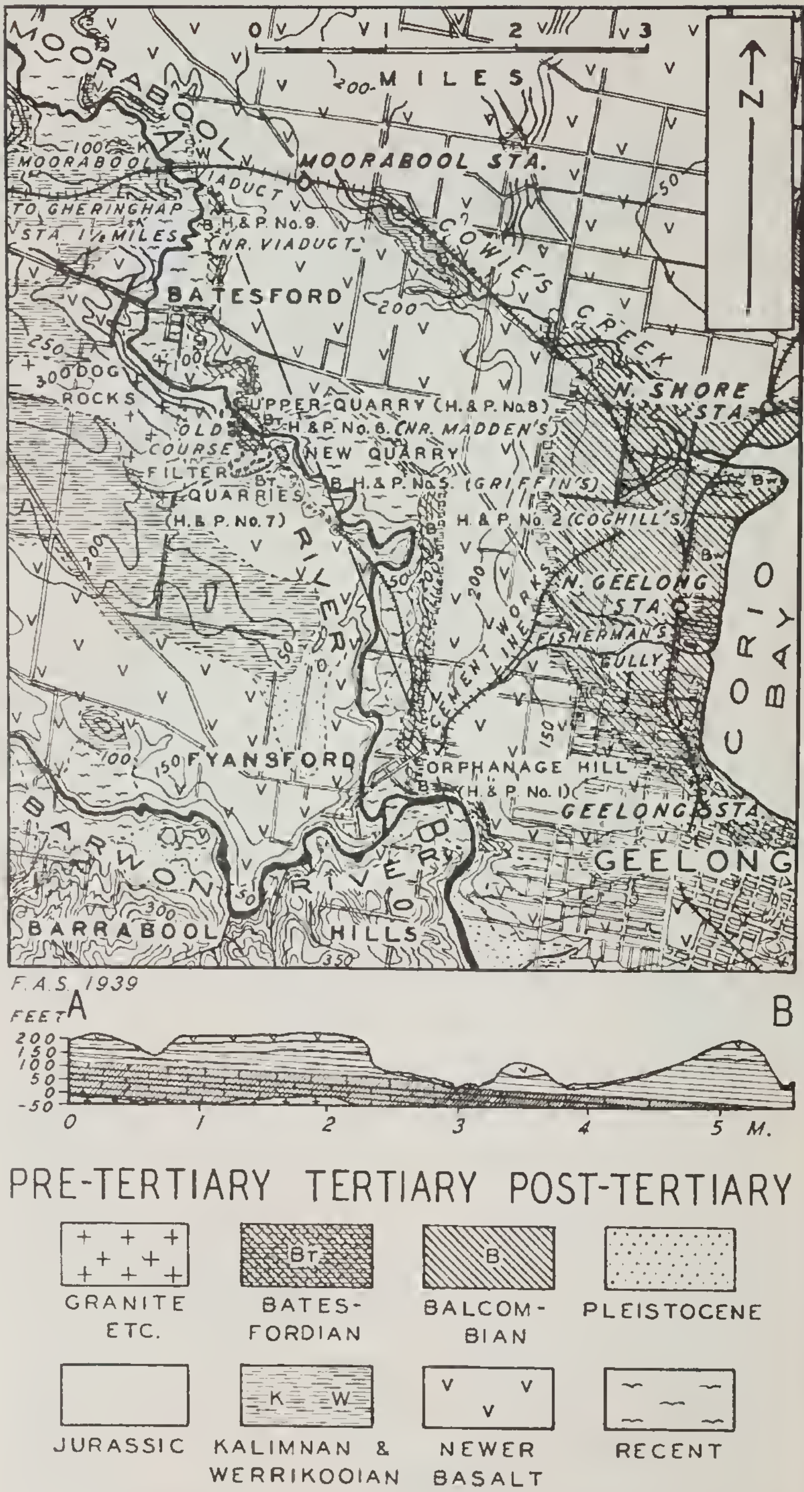



FIG. 5.—Geological map and section of Batesford district, near Geelong, Victoria. Modified from Quarter-sheets Nos. 24 N.E. and S.E., Geological Survey of Victoria, 1863, with emendations and additions. Contours from Geelong sheet, Military Survey of Victoria, 1914. Fossiliferous localities: B, Balcombian; Bt, Batesfordian; Bw, Barwonian; K, Kalimnan; W, Werrikooian.

[*Page 30.*

The other, on the right bank of the river about half a mile south of the building stone quarry, was known as the Dryden or Filter Quarries, formerly worked for lime-burning and cement-making, as well as for the manufacture of dripstone filters from the compact limestones at the base of the section. Chapman (299, p. 264) recorded the sequence, from below, as being 22 feet of pure white or cream-coloured friable limestone, composed largely of Lepidocyclinae, and gradually passing upwards into polyzoal rock with fewer Lepidocyclinae. Over this were 14 feet of fine-textured pale bluish clay.

Neither of these quarry sections is at present visible. The building stone quarry has been partly absorbed and partly covered by dump material from a greatly enlarged Upper Quarry adjoining to the south, formerly worked by Australian Cement Ltd. The Filter Quarries have been buried by dumps from this and from the company's new quarry on the right bank of the river, about a quarter of a mile further downstream. Upon development of the new quarry, the old upper quarry was abandoned in 1931, and the Moorabool River was diverted through it, since when much of the fine section on the east side has been obscured by slumping. Approximate thicknesses, from above, of this section are:—

(*g*) 6 feet Basalt.
(*f*) 16 feet White sands.
(*e*) 15 feet Brown ferruginous sands.
(*d*) 30 feet Yellow and grey clays and marls, more calcareous towards the base.
(*c*) 30 feet Earthy limestones.
(*b*) 30 feet White bryozoan limestone, weathering yellowish brown, and passing downwards into
(*a*) 45 feet Lepidocycline limestone.

172 feet

The floor of the quarry, now flooded, was below river level, and a shaft sunk below it disclosed a further 50 feet of lepidcycline and bryozoan limestone, towards the base becoming rich in granitic quartz grains derived from the adjacent Dog Rocks granite, which doubtless forms the bedrock. In the new quarry the limestones, which are at least 120 feet thick, are similarly overlain by about 30 feet of clays, here less oxidized and therefore grey in colour, which, like that of the filter quarries, contain a shelly fauna (107, p. 161) similar to that of the Fyansford clay (104, p. 19), with which they are continuous, and which the writer, like Hall and Pritchard, refers to the Balcombian.

*The Batesfordian may be defined as the interval of time represented by the deposition of the* Lepidocyclina-*bearing limestones of the Batesford quarries, as well as those represented therein by non-deposition or erosion.*

The limestone fauna of the Filter and Upper Quarries has been listed by Hall and Pritchard (104, p. 18; 107, p. 159), and by Chapman (299) in a study of the foraminifera, which were later also studied by Heron-Allen and Earland (324).

The characteristic foraminifera are:—

*Lepidocyclina (Nephrolepidina)* cf. *tournoueri* Lemoine and Douvillé, *L. (N.) martini* Schlumberger, *L. (N.) marginata* (Michelotti), *Cycloclypeus communis* Martin, *Operculina victoriensis* Chapman and Parr, *Amphistegina lessonii* d'Orbigny, *Rotalia verriculata* Howchin and Parr, *Gypsina howchini* Chapman. The commonest associated larger fossils are *Phyllacanthus duncani* Chapman and Cudmore and "*Chlamys*" *murrayanus* (Tate).

### Cheltenhamian Stage.

Here proposed for the fossiliferous ferruginous sandstones of the lower part of the coastal cliffs and the underlying "nodule bed" at Beaumaris, near Cheltenham, Port Phillip (31, 108).

The "nodule bed" appears above low tide mark on the axis of a gentle anticline immediately north-east of the boatshed and opposite the Hotel. It consists of a 3-inch layer of grit with well rounded clear quartz grains and larger subangular fragments of yellowish reef quartz, together with numerous ferruginous and slightly phosphatic concretions of cylindrical form, up to 5 or 6 inches in length. This nodule bed contains a rich fauna of sharks' teeth, of which *Isurus hastalis* (Agassiz) and *Heterodontus cainozoicus* (Chapman and Pritchard) are among the commonest, together with remains of other fishes and cetacean bones. The worn condition of many of the teeth suggests a remanié origin for some of the fossils, among which invertebrates are rare, though *Placotrochus deltoideus* Duncan, *Magadina* aff. *compta* (Sowerby), and *Zenatiopsis augustata* Tate occasionally occur.

The nodule bed, which marks a stratigraphic break, rests upon an eroded surface of impure limestone or calcareous sandstone, apparently the calcified and hardened upper portion of the Balcombian strata, chiefly marls, which form the sea floor below low tide mark opposite the boatsheds. From limestone pebbles of the beach shingle, derived from this older series, a small faunule (108) has been obtained which includes typical Balcombian mollusca such as "*Cerithium*" *apheles* T. Woods and *Pterospira hannafordi* (McCoy). At its highest point the nodule bed is about 1 foot above beach level, and is overlain by a 2-inch band of *Placunanomia* cf. *ione* (Gray), followed by ferruginous sandstones which are soon obscured by hill wash. Apparent dips of 1° S.S.W. and 1½° N.N.E. soon carry the nodule bed beneath the beach floor, which it occupies, however, between tide marks immediately south-west of the boatshed.

The cliff section (A) opposite the Beaumaris Hotel, at a spot 70 feet south-west of the boatshed and the centre line of Bodley-street, is as follows:—

(ix) 4 feet (?) white sands.
(viii) 6 feet ferruginous sandstone.
(vii) 8 feet ironstones.
(vi) 14 feet ferruginous sandy marl (?).
(v) 9 feet sandy marl with *Lovenia.*
(iv) 6 inches with decomposed shells (*Eucrassatella,* etc.).
(iii) 8 feet marly sands with calcareous concretions.
(ii) 1 foot fine sandy marl, with top 4 inches locally laminated.
(i) 6 inches calcareous sandstone, downward continuation hidden by beach sand.

51 feet.

Bed (i) appears lithologically similar to that *below* the nodule bed north-east of the boatshed, but the resemblance is probably due to secondary calcification, since here the nodule bed, exposed on the beach floor at low tide, must be about 1 foot below the base of the visible cliff section.

Bed (iii) is notable for undulations which, though perhaps in part concretionary, appear to be actual folds, possibly due to "slumping" after deposition. These "folds" are truncated by bed (iv), with very decomposed bivalves, of which the commonest is *Eucrassatella* cf. *camura* (Pritchard), and occasional quartz pebbles up to $\frac{3}{4}$ inch, also suggesting a break at the base of this bed. The succeeding bed (v) contains abundant *Lovenia forbesi* (T. Woods) and occasional *Monostychia* cf. *australis* Laube. Beds (vi) to (viii) are apparently unfossiliferous, but are largely masked at this spot, so that it is uncertain if (viii) continues to the top of the cliff or if (ix) is present. To the south-west, however, where the cliff top rises, bed (ix) constitutes a capping to the ferruginous beds of about 10 feet of white sands, perhaps Pleistocene, if they are the source of the extinct kangaroo remains which have been recorded from the beach shingle (605).

On the north-east of the boatshed the cliffs for about 300 yards are completely broken down and masked by vegetation, but good cliff sections occur from Ray-street eastwards. At a spot (B) 150 yards east north east of the steps leading to the former baths, a nearly vertical cliff section shows:—

(*d*) 8 feet white sands.
(*c*) 19 feet ferruginous sandstone with hard bands.
(*b*) 17 feet pale fine sandstone or sandy marl.
(*a*) 3 feet brown sandstone with shells near high water mark.

47 feet.

The nodule bed is not exposed, but may be reached by digging for about 2 feet in the beach shingle (108). Bed (*a*) at the base of the cliffs contains a typical shelly fauna, in which

*Limopsis beaumariensis* Chapman is perhaps the most abundant species. Bed (*b*) contains in its lower part *Neotrigonia acuticostata* (McCoy) and occasional large *Cucullaea praelonga* (Singleton), particularly just past a point (c) about 50 yards further easterly, where bed (*a*) contains hard shelly bands with *Eucrassatella* and *Aturia.*

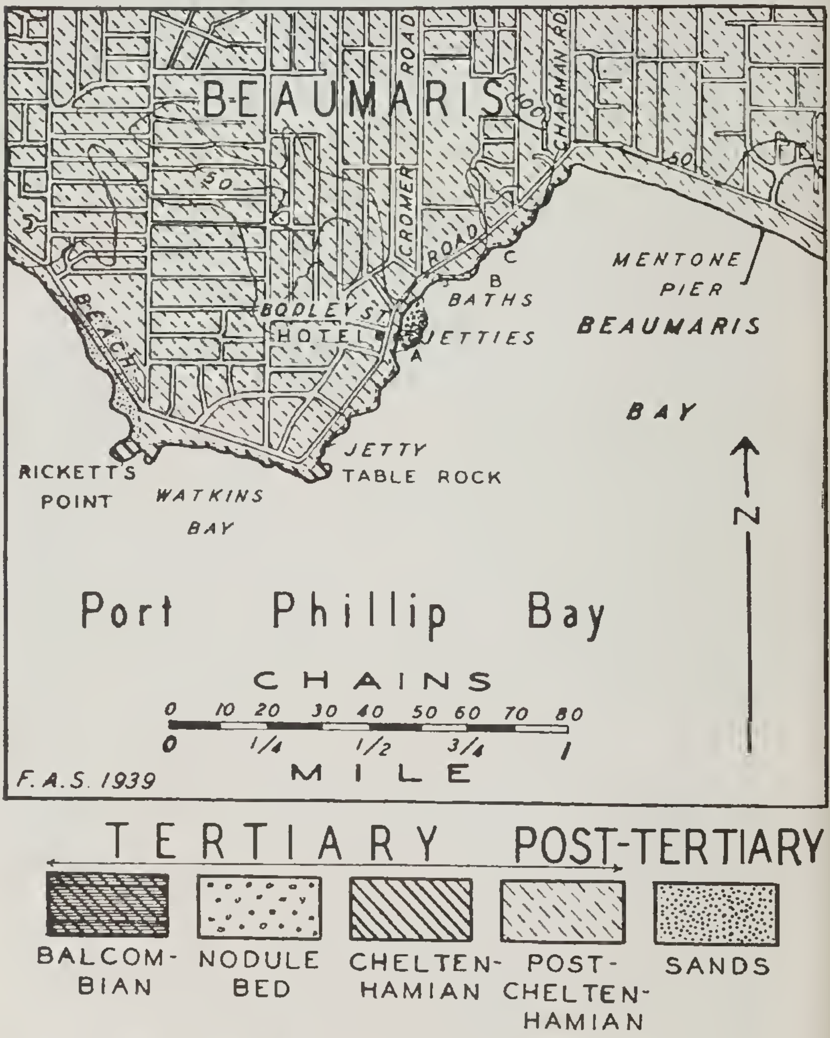



FIG. 6.—Geological map of Beaumaris, Victoria. Contours from Ringwood sheet, Military Survey of Victoria, 1915.

Beds (iii) to (v) of the section west of the boatshed cannot be recognized here, but the succeeding ferruginous sandstones are evidently represented by bed (*c*), and bed (ix) by bed (*d*).

Since bed (*d*) is probably Pleistocene and bed (*c*) may perhaps be Kalimnan or younger, it seems desirable to restrict the Cheltenhamian to the definitely fossiliferous beds beneath them, down to the nodule bed.

*The Cheltenhamian may be defined as the interval of time represented by the deposition of the nodule bed and of the overlying sandstones constituting beds (a) and (b) in the above sequence at Beaumaris, near Cheltenham, as well as those represented therein by non-deposition or erosion.*

At the type locality the fauna has been listed by Hall and Pritchard (108, pp. 191-197) and also by Dennant and Kitson (275), who did not, however, separate it from that of the strata below the nodule bed. Other names referring to this section are Cheltenham, Moorabbin, and Mordialloc.

Characteristic mollusca include:—

Pelecypoda: *Limopsis beaumariensis* Chapman, *Neotrigonia acuticostata* (McCoy), *Placunanomia* cf. *ione* (Gray).

EYRIAN.

This term was first introduced in 1926 by Woolnough and David (652, p. 340) in a vertical stratigraphical section at Muloowurtina, South Australia. In it they show 200 feet of strata, overlying the Winton Series of Upper Cretaceous age, and state "Eyrian Series (Tertiary).—Sandy shales. These contain fossil leaves of *Eucalyptus*, &c., in places." In the legend to the accompanying geological map (652, pl. 22) they add "Eyrian Series. Mesas of 'Desert Sandstone' with grey Shales, fresh-water. Occasional leaves of Banksia, Eucalyptus, &c. Possibly this Series is Cretaceo-Tertiary," though elsewhere (652, p. 349) they describe it as Older Tertiary to Miocene.

It would seem that these authors did not intend to propose a stage name, but only to name a local (even though widespread) series, and it has been used in this sense by E. J. Kenny (32, pp. 85-89), who thought the strata in the West Darling district of New South Wales which he referred to the Eyrian Series might "be assigned to the Lower Tertiary, pre-dating at least partially, if not wholly, the period of accumulation of the Marine Tertiaries of the Murray artesian basin."

David (2, table I, opp. p. 87), in referring the Eyrian Series provisionally to the Eocene, appears, however, to use it as a subdivisional term comparable to those proposed by Hall and Pritchard for the later marine formations.

The writer (*infra*, p. 51) believes the series may have an extended but perhaps somewhat younger range in time, possibly Oligocene to Miocene, though it must be admitted that the evidence of age is very slender.

It is here suggested that the original usage as the name of a series of strata developed in the Lake Eyre district of South Australia, and not as the name of a stage, be adhered to. The name Eyre Series, comparable with Winton Series, &c., would be preferable to the form Eyrian, but neither term need be further considered here.

### Gambierian Stage.

This term was introduced in 1916 by Chapman (57, p. 381), in referring the lower beds of the Mallee bores of North-West Victoria to "Miocene (Janjukian with a Gambierian facies)," which is stated in a footnote to be "Typically represented by the white polyzoal limestone of Mount Gambier, South Australia." This limestone was, however, placed by Hall (103) with the Balcombian of Muddy Creek, Western Victoria, with which beds Tate and Dennant (185) had also associated it.

The name Gambierian was omitted by Chapman from his discussion later in the same paper (57, pp. 409, 411) of the subdivisions of the Tertiary beds, and it seems desirable to follow suit and leave the name in abeyance until such time as it may be proved to be a stage in the Barwonian System not comprehended in either the Balcombian or the Janjukian stage.

### Giralian Stage.

Proposed herein for the *Discocyclina* limestones between Giralia and Bullara, near the head of Exmouth Gulf, in the North-West Division of Western Australia (fig. 1). These constitute a thin series, 10-30 (?) feet in thickness, resting with a disconformity upon the Cardabia series (Turonian-Campanian) of the Upper Cretaceous, which latter is exposed by erosion of the eastern limb of the shallow Giralia anticline. Their relationship to the thick *Lepidocyclina* limestones, probably Upper Oligocene to Lower Miocene, of the Cape Range, some 20 miles to the north-west, is as yet unknown.

Since field knowledge (73, 74, 156) of the *Discocyclina* limestones remains virtually restricted to the fact of their occurrence at two localities on the track between Giralia and Bullara, at the northern end of the Giralia Range, and at Red Bluff and Cape Cuvier (78), on the coastline 120 miles to the south-south-west, selection of a type section is not at present desirable.

*The Giralian may be defined as the interval of time represented by the deposition of the* Discocyclina-*bearing limestones of North-Western Australia, as developed between Bullara and Giralia, as well as those represented therein by non-deposition or erosion.*

The foraminifera of the two localities in the Bullara area have been determined by Chapman and Crespin (306), from whose identifications the following may be selected as characteristic: *Pellatispira orbitoidea* (Provale), *P. inflata* Umbgrove, *Discocyclina pratti* (Michelin), *D. dispansa minor* Rutten, *Asterocyclina* cf. *stellata* (d'Archiac), and *Nummulites* sp., the last being recorded only from the second locality, and *Asterocyclina* only from the first.

## Hamiltonian.

A term used in 1922 by Mawson and Chapman (640, p. 146) in the form Hamiltonian facies, defined in a footnote as "A regional word, here coined to express the combined faunas of the lower and upper Muddy Creek beds with the intercalated limestone of the Grange Burn, ranging from the Balcombian to the Kalimnan."

But the Grange Burn limestone with lepidocyclinae (at that time referred by Chapman to the Janjukian, but by the present writer to the Batesfordian), instead of being intercalated, is actually antecedent to the lower beds (Balcombian of Clifton Bank) at Muddy Creek, as originally maintained by Dennant (83) and since proved by the Muddy Creek bore. The term Hamiltonian can only be used for a system comprising (in terms of the present writer's views as to sequence) the Batesfordian, Balcombian, and Kalimnan stages. It thus overlaps the earlier proposed and better known Barwonian system, and is only a comprehensive term for the whole of the marine Tertiary strata of the Hamilton district, which are referable to stages already defined.

It is therefore suggested that the name Hamiltonian is unnecessary and should be abandoned, as has been done, indeed, by Chapman himself.

## Janjukian Stage.

This, probably the most important stage in point of size, was introduced by Hall and Pritchard (112, pp. 78, 79) in 1902, with slightly different spelling, as follows:—"Jan Jucian.—The section near Spring Creek, on the coast of Bass Strait, south of Geelong, is in the main in the Parish of Jan Juc, and its fauna differs greatly from that of Balcombe's Bay. . . . The township near Spring Creek is called Torquay, but the use of this name in England renders another advisable. The older name for Torquay was Puebla, but the employment of this name, again, would lead to confusion with certain American strata. The name Jan Juc remains, and is referred to by McCoy as the locality whence several of his fossils came."

The coastal section referred to by Hall and Pritchard extends along Half Moon Bay, in the Parish of Jan Juc, for about 3 miles south-westerly from a point immediately south of Torquay, a township 13 miles south of Geelong, Victoria. The strata form a broad half-dome whose centre is a few yards south-west of the rock stack known as Bird Rock, from which the lower beds, with a rich molluscan fauna, outcrop near the base of the cliffs opposite, known as Bird Rock cliffs, as far as Fisherman's Steps, about a mile to the south-west.

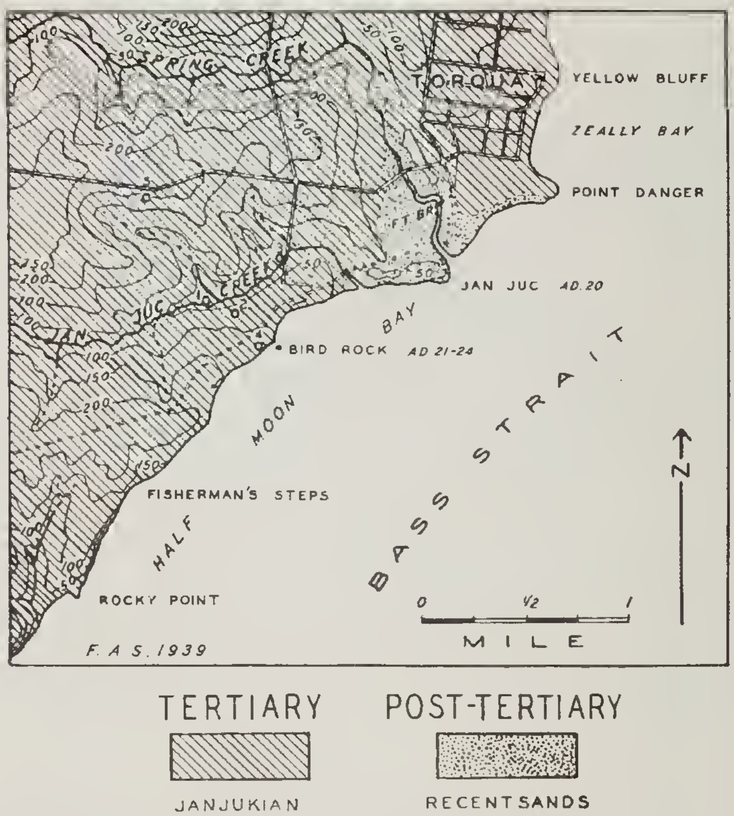



FIG. 7.—Geological map of Torquay District, Victoria. Modified in part from Quarter-sheet No. 28 S.E., Geological Survey of Victoria, 1863. Contours from Anglesea sheet, Military Survey of Victoria, 1915.

On either limb of the fold the upper beds, chiefly bryozoan limestones with echinoids, &c., are brought down towards beach level by low dips of about 4°–6°, and form on the north-east the cliffs between Bird Rock and the mouth of Spring Creek, and on the south-west those between Fisherman's Steps and Rocky Point, along which cliffs the impure limestones (" echinoderm-rock ") are overlain by a younger series of shelly clays.

A good account of the section has been given by Tate and Dennant (183, p. 206; 184, p. 118), who recognized only a division into upper and lower beds, the former including both limestones and upper clays, and the latter the richly fossiliferous sandy clays and marls, often glauconitic, at or near the horizon of Bird Rock. This was accepted by Hall and Pritchard (107, p. 156), though Daintree, who had first made a twofold division (28), later adopted a threefold division (marginal notes to quarter-sheet 28 S.E., Geological Survey of Victoria, by Daintree and Wilkinson, 1863). More recently Chapman and Singleton (27, p. 994) have described the sequence of the upper beds, and also those in deep borings (27, p. 996), while Pritchard (155, p. 935) has proposed on palaeontological grounds seven sets of beds. Of these, the present writer identifies the Scutellina Limestones as those of the point and rock stack, immediately south of the mouth of Spring Creek, marked on the military survey map as Jan Juc, a name given on quarter-sheet 28 S.E. to the first point north-east of the mouth of Spring Creek, now known as Point Danger, and the Cellepora Limestones as those of the cliffs between the mouth of Jan Juc Creek and Bird Rock. Descending stratigraphically, the Ancilla Clays and the Septarian Limestones apparently belong to the upper part of the cliff section, about 180 feet in height, opposite Bird Rock; the Chione clays are regarded as the richly fossiliferous glauconitic clays *above* the hard band which caps Bird Rock; and the Glycymeris beds and the Limopsis beds as the sandy marls *below* the same hard band, which Hall and Pritchard identified (107, p. 155) as that dividing Daintree's upper and lower beds. The greater part of the fossils listed from the locality, which has variously been termed Spring Creek, Bird Rock Bluff, and Torquay, come from the last three of Pritchard's subdivisions.

Since it is hoped in the near future to furnish a detailed account of the stratigraphy and successive faunules of this important section, it is advisable for the present to define the stage in somewhat general terms. It is unfortunate that the cores of the deep borings made by the Torquay Oil Wells Company are unavailable for examination, but an earlier shallow bore reported on by Chapman (267) proved a downward extension of the lower beds of the Bird Rock Cliffs for 70 feet, while Chapman and Singleton (27, p. 996) stated similar greensands and marls to occur at 170 feet below sea level, and it seems reasonable to extend the Janjukian downward to this depth. Pritchard (155, p. 936) claimed a total thickness (inclusive of 183 feet in outcrops) of rather more than 1,000 feet for the marine series, but since lignitiferous sands with *Cyclammina* (here referred to the Anglesean) were reported between 840 and 410 feet below sea level (27, p. 996), much of this cannot be regarded as Janjukian.

*The Janjukian may be defined as the interval of time represented by the deposition of the marine beds outcropping in the coastal sections, about 3 miles in length, between Rocky Point* *and the mouth of Spring Creek, in the Parish of Jan Juc, and proved in borings to a depth of 170 feet below sea level, as well as those represented therein by non-deposition or erosion.*

The fauna of the type locality, under the name of Spring Creek, but without subdivision into upper and lower beds, has been listed by Tate and Dennant (183) and by Dennant and Kitson (275). The fossils from the limestones of the upper beds have been recorded by Hall and Pritchard (107, p. 162) and those of the upper clays by the same authors (107, p. 163) and by Tate and Dennant (183, p. 210; 184, p. 119).

The characteristic mollusca of the lower beds (below the summit of Bird Rock) include:—

Pelecypoda: *Limopsis chapmani* Singleton, *Glycymeris (Grandaxinaea) ornithopetra* Chapman and Singleton, *Eotrigonia semiundulata* (Jenkins), *Venericardia janjukiensis* Chapman and Singleton.

Gasteropoda: *Volutospina anticingulata* (McCoy), *Polinices wintlei* (T. Woods).

Less common but apparently restricted species include:—

Gasteropoda: *Umbilia platyrhyncha* (McCoy), *Pterospira macroptera* (McCoy), *Belophos woodsii* (Tate).

Cephalopoda: *Spirulirostra curta* Tate.

## Kalimnan Stage.

This was proposed by Hall and Pritchard (112, p. 78) in 1902 as follows: "Kalimnan.—The beds at Jimmy's Point, near the mouth of the Gippsland Lakes, are near the township of Kalimna. They were referred to Older Pliocene by Sir F. McCoy, and by Mr. Dennant to Miocene."

The sandy clays and associated shell beds of the type locality, Jimmy's or Jemmy's Point, also referred to as Kalimna, in Eastern Victoria, have been briefly touched upon by Dennant (85) and by Dennant and Clark (90), but hitherto have not been described in detail. A natural section, not more than 10 feet in height, is given by the low cliffs which extend from Kalimna Hotel jetty eastwards for three-quarters of a mile past Jemmy's Point to the bridge which connects the latter with Lakes Entrance township.

The sequence of the strata at Jemmy's Point is well shown by the cuttings along the road which joins this bridge across the North Arm with the township of Kalimna. In stratigraphic order from above downwards it is as follows:—

(*m*) 20 + feet light grey and reddish sands.
(*l*) 30 feet reddish brown clayey sands, with stratification and sporadic pebbles.
(*k*) 4 inches pebble band, discontinuous, including rhyolite pebbles.
(*j*) 8 inches carbonaceous layers in fine sandstone.
(*i*) 3 feet foraminiferal silt.

(*h*) 1 foot upper shell bed, somewhat irregular and thinning out to W.
(*g*) 1 foot 6 inches hard laminated sandstone.
(*f*) 13 feet sandy marls with concretionary bands.
(*e*) 4 inches hard band.
(*d*) 13 feet sandy marl and concretionary sandstones.
(*c*) 2 feet lower shell bed, sandy marl with *Eucrassatella*, etc.
(*b*) 2 feet 6 inches concretionary sandstone with a few *Turritella* near top.
(*a*) 3 feet 6 inches fine sandstone to base of section, about 2 feet above high water mark.

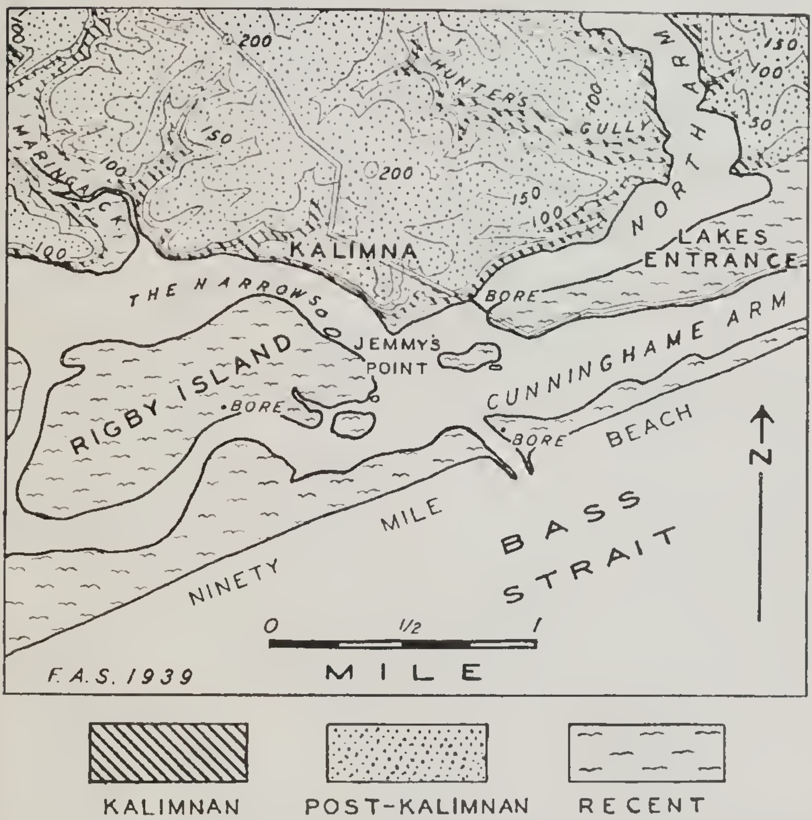



Fig. 8.—Geological map of Kalimna district, East Gippsland, Victoria. Modified from geologically coloured and contoured parish plan of Colquhoun, Geological Survey of Victoria, 1929.

Pebbles, though very rarely present in the upper shell bed (*h*), are common on the unfossiliferous beds which succeed the silt bed (*i*), in which W. J. Parr has recognized abundant *Nonion victoriense* (personal communication), and which is here taken as the upward limit of the Kalimnan at this locality. Beds (*j*)–(*m*) are therefore believed to be an Upper Pliocene or Pleistocene series, probably non-marine, resting disconformably on the Kalimnan strata (*a*)–(*i*). Macro-fossils are almost entirely confined to the shell beds (*c*) and (*h*) and to the upper part of (*b*), but are known to occur in depth in No. 1 Government Bore, Parish of Colquhoun (No. 3, Lakes Entrance), situated at about 9 feet above high water mark, near the north-western end of the bridge. This bore (25, p. 13; 38, p. 89) showed the Kalimnan strata to persist, with a rich fossil zone about 10 feet thick, first met with at 90 feet, down to a depth of 140 feet, being underlain by pre-Kalimnan Tertiary strata till the granitic bedrock is reached at 1,404 feet.

It is reasonable to add to the exposed Kalimnan strata (*a*)–(*i*), totalling 40 feet, a further 133 feet proved in the bore, giving a total of 173 feet of Kalimnan beds at the type locality.

*The Kalimnan may be defined as the interval of time represented by the deposition of the sandy marls and sandstones constituting beds (a)–(i) in the above sequence at Jemmy's Point, Kalimna, together with similar beds down to* 131 *feet below sea level, proved by boring at this locality, as well as those represented in the preceding by non-deposition or erosion.*

At the type locality the foraminifera have been identified by Parr (339), and the mollusca and a few other groups listed by Dennant (85), with subsequent alterations and additions (90). The records by Dennant and Kitson (275) are not confined to Jemmy's Point, in the fauna of which there remains a substantial undescribed residue.

Characteristic species of foraminifera, which occur throughout the outcropping beds, are *Glandulina kalimnensis* Parr, *Planulina kalimnensis* Parr, *Nonion victoriense* Cushman, *Flintina intermedia* (Howchin).

The characteristic mollusca of the lower shell bed (*c*) are:—

Pelecypoda: *Cucullaea praelonga* (Singleton), *Glycymeris* (*Veletuceta*) *paucicostata* Pritchard, *Ostrea arenicola* Tate, *Neotrigonia howitti* (McCoy), *Chlamys asperrimus antiaustralis* (Tate), *Anomia tatei* Chapman and Singleton, *Venericardia trigonalis* (Tate), *Eucrassatella kingicoloides* (Pritchard), *Clausinella* (*Placamen*) *subroborata* (Tate), *Notocallista* (*Striacallista*) *submultistriata* (Tate), *Bassina paucirugata* (Tate).

Gasteropoda: *Turritella* (*Colpospira*) *conspicabilis* Tate, *Tylospira coronata* (Tate), *Polinices* (*Conuber*) *cunninghamensis* (Harris), *Merica wannonensis* (Tate), *Nassarius crassigranosus* (Tate).

In the upper shell bed (*h*) the characteristic mollusca are:—

Pelecypoda: *Nucula* (*Ennucula*) *kalimnae* Singleton, *Nuculana* (*Scaeoleda*) *crassa* (Hinds), *Glycymeris* (*Veletuceta*) *paucicostata* Pritchard, *Neotrigonia howitti* (McCoy), *Clausinella* (*Placamen*) *subroborata* (Tate), *Aloidis* (*Notocorbula*) *coxi* Pilsbry.

Gasteropoda: *Bankivia howitti* Pritchard, *Leiopyrga quadricingulata* Tate, *Polinices (Conuber) cunninghamensis* (Harris), *Merica wannonensis* (Tate), *Nassarius crassigranosus* Tate.

### Murravian Stage or System.

The first use of the term Murravian appears to have been in 1878 by Tate (171, p. 123), who listed the corals of the River Murray cliffs under the heading "Upper Murravian Series." He used the term in the sense of a local series rather than as a stage name, and on the preceding page referred to "the middle and lower Murray series." He also gave a generalized section of the strata of the River Murray cliffs, as follows (171, p. 121):—

"1. Lacustrine (?) sand and marls. No fossils, exceeding 60 feet in thickness.
2. Upper Marine Series; shelly limestones (false bedded) and oyster beds, with occasional argillaceous and sandy beds. Rich in gasteropods and corals. About 50 feet thick.
3. Middle Marine Series; usually a yellow calciferous sandstone; 40–45 feet thick. Rich in echinoderms, brachiopods, pectens, and polyzoa.
4. Lower Marine Series; Ferruginous sandstones and polyzoan limestones. Rich in echinoderms and brachiopods, but for the most part of different species to those in the upper beds."

In the following year, Tate repeated this subdivision in a correlation table (47, p. liii):—

"Upper Murravian. Shell limestones, oyster beds, and sands.
Middle Murravian. Calciferous sandstone with polyzoa.
Lower Murravian. Ferruginous sandstone and polyzoal limestone."

Finally, in 1885, Tate (175) discussed fully the stratigraphy of the Murray River cliffs, illustrated by measured vertical sections at three localities: near Glenforslan, 4 miles north from Blanchetown; at North-West Bend Head Station; and at 4 miles south from Morgan. The Upper Murravian was restricted to the oyster banks (characterized by *Ostrea sturtiana* Tate), the underlying beds, with a rich gasteropod fauna at the locality 4 miles south of Morgan, being transferred to the Middle Murravian. Of the Lower Murravian, which is exposed only at the first of the above sections, he remarked (175, p. 41):—"This series is characterized rather by lithological than by palaeontological characters, which latter are somewhat negative, as the species are few in number and somewhat sparsely distributed. It is often highly charged with gypsum, and then fossils are rarely present."

The upper beds, whose fossils are usually poorly preserved, largely as casts, rest in places upon an eroded surface of the middle beds, as at North-West Bend (185, p. 119). These middle beds, at all events the shelly clays at the locality 4 miles below Morgan, the writer provisionally places in the Balcombian, a correlation previously implied by Tate (181), though they were referred by Chapman (57, p. 411) to the Janjukian. The unconformably overlying upper or oyster beds have nearly always been placed (44, 57, 112, 185) in the Kalimnan, but the evidence is by no means conclusive and the beds may well be somewhat older.

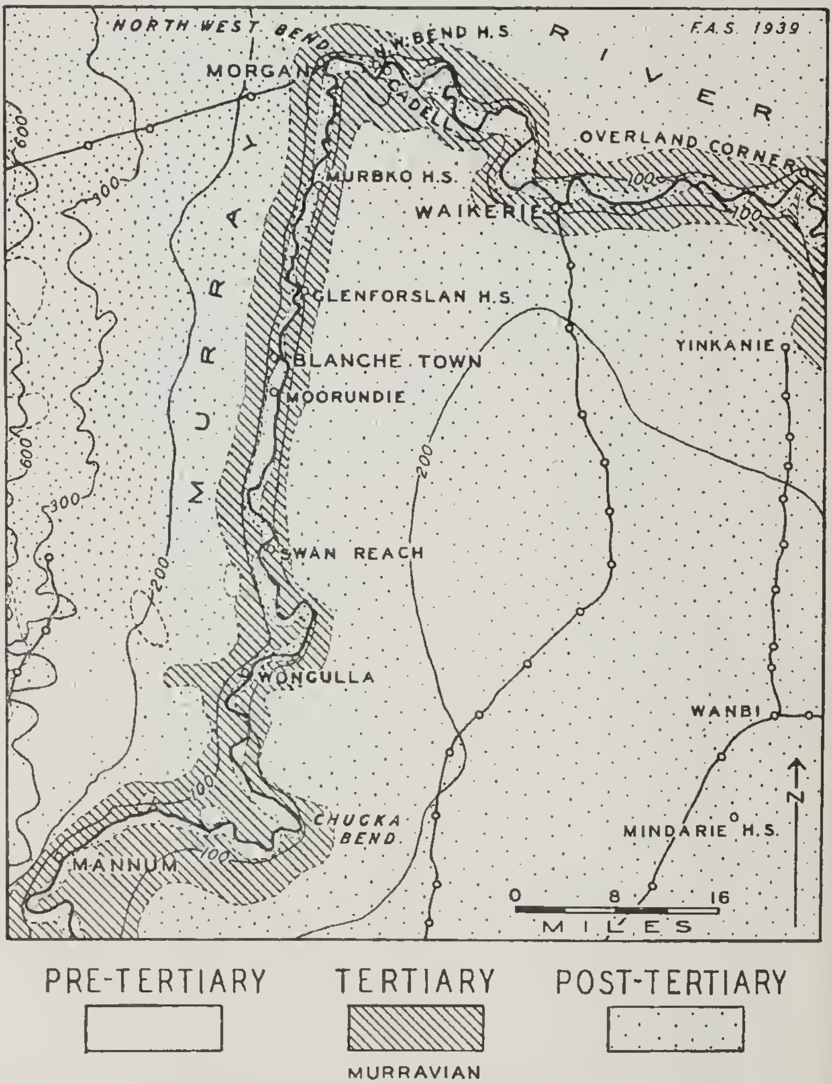



Fig. 9.—Geological map of part of the Murray River basin, South Australia. Modified from maps of the South Australian Departments of Lands and Mines. Contours modified from Adelaide sheet, International Map of the World 1: 1,000,000, and railway heights.

The term Murravian was not considered by Hall and Pritchard (112) in their discussion on nomenclature, and the writer is opposed to its use as a stage or system name for reasons similar to those advanced in respect to the Hamiltonian. Since its use in the form Murravian series has recently been revived by E. J. Kenny (32, p. 93), it is desirable to give a more precise definition. It is difficult to select a single type locality, since at the section 4 miles below Morgan, from which Tate obtained nearly all his fossils, his Lower Murravian is not present, and at other sections where it occurs all the strata are poorly fossiliferous. The definition must therefore be in somewhat general terms.

*The Murravian may be defined as the interval of time represented by the deposition of the marine beds outcropping in the River Murray Cliffs between Blanchetown and North-West Bend, South Australia, as well as those represented therein by non-deposition and erosion.*

The fauna has been listed by Tate, and the species of the three divisions discussed (175, pp 35-41), while Dennant and Kitson (275) have not distinguished between those of the two lower divisions.

### Werrikooian Stage.

Defined in 1902 by Hall and Pritchard (112, p. 77) as follows:— "Werrikooian. The Limestone Creek beds on the Glenelg River are in the Parish of Werrikoo, in the County of Follett. They have been referred to Pleistocene and to Pliocene. There is another Limestone Creek, near the head of the Murray, in Victoria, which yields Palaeozoic fossils, and a third in the County of Heytesbury, with Older Tertiary fossils."

These beds were first described, under the name Bankivia Beds, by Dennant (82, 84), who regarded them as deposited in a former estuary of the Glenelg River, cut through the Ostrea Limestone and the underlying "coralline" [i.e., bryozoan] limestone of Older Tertiary age. The writer (44, 159) has since shown that at the section on the right bank of the Glenelg River in allotment 68, Parish of Werrikoo, known as Caldwell's Cliff, the Werrikooian shell bed rests unconformably on Barwonian bryozoan limestone and is itself conformably overlain by sandy limestones which are capped by the Ostrea Limestone.

The localities visited by Dennant occur in the Glenelg River valley in the Parishes of Werrikoo, Killara, and Myaring, and extend from the junction of Limestone Creek to Roscoe's Cliff, in the Parish of Killara, about 3½ miles to the north. At none of them is the shell bed satisfactorily developed *in situ*, so that as a type locality Caldwell's Cliff, nearly 2 miles south of the junction, is here selected.


Fig. 10.—Geological map of the Glenelg River valley near Limestone Creek, South-Western Victoria. Modified from geologically coloured and contoured parish plans of Killara, Myaring, and Werrikoo, Geological Survey of Victoria, 1937-8, with additions. Bw. Barwonian fossils. W. Werrikooian fossils.

At this locality, first discovered by J. J. Caldwell of the Geological Survey of Victoria, the sequence measured by the writer is as follows:—

(*m*) 4 feet sandy soil.
(*l*) 2 feet 4 inches oyster bed with *Pecten* (*Notovola*) *meridionalis.*
(*k*) 10 feet 6 inches laminated and cross-bedded limestone with sporadic oysters.
(*j*) 6 feet limestone with abundant irregular concretions.
(*i*) 3 feet 4 inches flaggy limestone.
(*h*) 6 inches oyster band with *Equichlamys bifrons* and mould of *Dosinia.*
(*g*) 1 foot 6 inches limestone.
(*f*) 8 inches oyster band with quartz pebbles.
(*e*) 3 feet limestone.
(*d*) 6 inches oyster band with *Placunanomia,* locally with a 2-inch clayey capping.
(*c*) 8 feet limestone with sporadic oysters and other bivalves (*Placunanomia. Glycymeris*), chiefly in a 4-inch grit band 2 feet above its base.
(*b*) 1 foot shell bed, resting unconformably on
(*a*) 53 feet bryozoan limestone, largely masked by slip material.

The top 3 inches of bed (*a*), of Barwonian age, is bored by *Barnea*, casts of which may be found *in situ.* Bed (*b*), which contains the typical Werrikooian fauna, differs in appearance from the sparsely fossiliferous limestones (*c*)–(*h*) which follow, but the relation is one of conformity, and the same apparently applies to the succeeding beds up to (*l*), which is the well-marked Oyster Bed of the district. This latter is referable to the Ostrea Limestone of Dennant (84), but whether beds (*i*)–(*k*) should be included also is debatable.

Shell bed (*b*), containing a fauna of 200 molluscan species, with about 5 per cent. of extinct species and an extinct genus, is referred by the writer to the summit of the Pliocene, and the succeeding strata may well bridge the boundary of the Pleistocene. For field mapping it is probably best to assume that the beginning of the Pleistocene is marked by the incoming of *Pecten* (*Notovola*) *meridionalis* Tate. Provisionally beds (*c*)–(*i*) may be referred to the Werrikooian and beds (*j*)–(*l*) to the conformably succeeding Pleistocene.

*The Werrikooian may be defined as the interval of time represented by the deposition of the shell bed and sandy limestones constituting beds (b)–(i) in the above sequence at Caldwell's Cliff, Glenelg River, in the Parish of Werrikoo, as well as those represented therein by non-deposition or erosion.*

The fauna at the type locality as above defined has been studied by the writer, but results are not yet published. The original lists given by Dennant (82, 84), based on identifications by Tate, and the slightly amended list of Dennant and Kitson (275), all need considerable revision, not only in nomenclature but also because they include a number of extinct species actually derived from the underlying Barwonian (? Balcombian) marls, which outcrop near river level at several localities.

Some of the characteristic molluscan species are as yet undescribed, but the remainder include:—

Pelecypoda: *Nucula* (*Ennucula*) *kalimnae* Singleton, *Nuculana* (*Scaeoleda*) *crassa* (Hinds), *Glycymeris* (*Veletuceta*) cf. *striatularis* (Lamarck), *Chlamys asperrimus dennanti* Gatliff and Singleton, *Zenatiopsis angustata* Tate, *Clausinella* (*Placamen*) *placida* (Hanley).

Gasteropoda: *Bankivia fasciata* (Menke), *Turritella* (*Ctenocolpus*) *terebellata* Tate, *Polinices conicus* (Lamarck).

On the left bank of the Glenelg River at Dartmoor, immediately south of the railway, the following section recalls lithologically the upper part of Caldwell's Cliff:—

(*d*) 14 feet false bedded and thinly laminated limestone, with *Pecten meridionalis* at 5 and 7 feet above base.
(*c*) 5 feet irregularly nodular limestone, with a few oysters at the top.
(*b*) 8 inches oyster bed with *Pecten meridionalis* and *Placunanomia*.
(*a*) 12 feet flaggy limestones, downward extension obscured by talus down to rail level

At both localities the general sequence is similar and the beds appear to be beach or dune deposits, with a marine incursion represented by the oyster bed. This latter, characterized by an oyster which is probably a new subspecies of *Ostrea sinuata* Lamarck, does not occupy the same position in the Dartmoor section, of which beds (*b*)–(*d*) must be referred to the Lower Pleistocene on the criterion suggested above. Since the lower part of the section is obscured by talus, it is uncertain if bed (*a*) is underlain by the Werrikooian shell bed.

## Yallournian.

This term was introduced in 1935 by the writer (17, p. 128 and footnote), with the brief statement "Proposed for the lignites and clays of Yallourn."

At Yallourn, in the Parish of Narracan, Gippsland, Victoria, the State Electricity Commission's open cut has exposed 200 feet of lignite overlain by 30 feet of freshwater clays capped by sands.

A deep boring nearby, No. 471, Parish of Narracan (38, p. 144), shows:—

20 feet clay and sand.
237 feet brown coal.
1 foot ligneous clay.
5 feet brown coal.
4 feet ligneous clay.
8 feet brown coal.
48 feet clay.
48 feet brown coal.
20 feet clay.

436 feet depth bored from surface level at 128 feet.

Since, for purposes of correlation, stage names should preferably be based on marine formations, the same objections apply to the Yallournian as to Eyrian, to which, indeed, it may be partially equivalent in time. It is therefore best regarded as a series, preferably in the form Yallourn Series, and not as a stage name.

## Non-Marine Deposits.

For reasons already indicated the non-marine Tertiary deposits can be discussed in only a very approximate chronological order. The following allocations are thus tentative.

### Eocene.

Amongst the earliest non-marine deposits, if indeed they are Tertiary, are the unfossiliferous grey shales, sandy clays and sands, apparently of fresh-water origin, reported between 780 and 1,950 feet in King's Park Bore No. 2, near Perth, by Parr (338), who has referred the overlying series, more than 500 feet in thickness, of foraminiferal shales and intercalated sandstones, to the Upper Eocene. But at depths between 1,650 and 1,750 feet in other borings in the Perth area, Miss Crespin has found foraminifera referred to the Lower Cretaceous (338, p. 71), so that while the fresh-water deposits of the King's Park bore are not younger than Upper Eocene, their Tertiary age is not fully established.

### Oligocene.

Either Oligocene, or older, are the leaf-bearing pipe-clays of Berwick (238, 240, 636), Narracan (235, 254, 644, 652*a*), and Pascoe Vale (253, 623), which underlie the basalts of the older volcanic series of Victoria, since the basalt of Pascoe Vale may be traced to Royal Park, where littoral marine beds of probably Balcombian age rest on its eroded surface (108, 158). Doubtfully to be placed with them are the "deep leads" (buried fluviatile deposits) of Welcome Rush (45,650) near Stawell, and of the Upper Moorabool River (106, 647) in Victoria, both overlain by marine strata, in the latter case the lower Maude beds of Janjukian age.

Probably Oligocene in the main are the important deposits of lignite or brown coal which, in South Australia and more particularly in Victoria, appear to be pre-Barwonian or else contemporary with the earliest marine stages, probably Anglesean. With their associated sands and clays they have been called by the author Yallournian (17), from their development in Gippsland at Yallourn (624) and elsewhere in the Latrobe Valley, in which seams exceeding 500 feet constitute the thickest perhaps in the world.

From their upper part at Yallourn is a florule (245), in which *Banksia* is dominant, occurring sporadically in the lignites, which otherwise contain no plant remains except coniferous wood (200, 202). To the east these beds appear correlable, in their lower portion at least, with the lignites and clays of the deep borings in the Lake Wellington and Lake Victoria district of East Gippsland (Fig. 15), which are overlain by the Barwonian marine beds of the East Gippsland region, whose earliest part is above referred to basal Miocene or late Oligocene. Sussmilch (18) has urged that such great total thicknesses of lignite, of the order of 800 feet, indicate that the Yallournian must cover an extended period of time, in his view up to the Lower Pliocene. While there is force in his argument that all the lignites are not of the same age, and there is evidence of interdigitation of lignites and ligneous clays with marine beds in bore No. 2, Parish of Nuntin (41), bore No. 1, Parish of Goon Nure (40) and bore No. 1, Parish of Boole Poole (41), these latter are probably Anglesean, and it is likely that the bulk of the Yallourn series is pre-Miocene, as are probably the lignites, sands and clays of Altona (23, 108, 638, 648) and Parwan (38), to the north-west of Port Phillip, which are overlain by marine Balcombian, and those of Moorlands (613, 640) in South Australia, overlain by marine Barwonian strata.

Approximately equivalent to them in age are the clays and sands at the base of the Point Addis bores (38, p. 17), and bores at Dartmoor (38, p. 91) on the Glenelg River, in Victoria, and the carbonaceous sands and pipe-clays of Maslin's Bay near Aldinga, in South Australia, in which plant remains occur (236).

Perhaps to be correlated with the Altona lignitic series are the sands, clays, and impure lignite of the Balcombe Bay bore (36, p. 30), likewise overlain by marine Balcombian, but here underlain by basalt.

The age of beds containing the so-called "*Cinnamomum* flora," but which do not come into relation with marine deposits, cannot always be established. Those of Narracan (235, 254, 644) underlying the "Older Basalt" have above been referred to the Oligocene, and with them may be placed the Elsmore and Vegetable Creek (Emmaville) leads (18, 246), also sub-basaltic, of northern New South Wales, and across the Queensland border the Redbank Plains series (633) near Oxley and Darra, with fish-remains which have been regarded as Oligocene (585). Since the Silkstone series (633) of S.E. Queensland, with shales, sandstones, Planorbis limestones, and contemporary basalts, conformably succeeds the Redbank Plains series, it may likewise be provisionally referred to the Oligocene (616).

As elsewhere suggested by the author (17), the *Cinnamomum* flora probably extends, at least in Victoria, from Oligocene to

Upper Miocene, and Sussmilch's view (18) that it, and indeed all the plant-bearing beds, may be referred to the Lower Pliocene, appears untenable (645, 663).

## Miocene.

The Eyrian series of lacustrine sandstones and shales, unconformably overlying the Upper Cretaceous Winton series, is typically developed in the vicinity of Lake Eyre in South Australia, but extends into Queensland. Though originally regarded by Woolnough and David (652, p. 349) as "Older Tertiary to Miocene," David later (2) transferred it provisionally to the Eocene. These Eyrian strata in places contain leaves, including *Eucalyptus* and *Cinnamomum*, and Chapman (237) has referred many localities to the lower Oligocene. They may, however, even be Miocene, and it is likely that the Eyrian (or Eyre series) has an extended range in time, perhaps from Oligocene to Miocene, or even later.

The plant-bearing beds (622) and "deep leads" (29, 232, 628) of Eastern Australia probably cover a similar range, but provisionally to be placed in the Miocene are the quartzites with *Cinnamomum* of Dalton (18, 246), near Gunning, and the leaf beds of the Warrumbungle Mts. (244) and of the Darling Plains (237) in New South Wales; the sands, clays, and ironstones (28) with *Cinnamomum* which overlie "Older Basalt" at Bacchus Marsh, Victoria; and perhaps the leaf beds of Macquarie Harbour in Tasmania. It must be admitted, however, that the flora shows much resemblance to that of localities such as Narracan, which are above included as Oligocene. Certainly not older than Miocene are the pipe-clays of Sentinel Rock (50, 110) on the Aire coast in Victoria, which overlie marine Barwonian beds and contain a distinctive flora in which *Coprosmaephyllum* and *Persoonia* are common (195, 238, 243).

Elsewhere evidence of age is seldom definite, though occasionally leaf remains are entombed in marine deposits, such as the Plantagenet beds of Cape Riche (271) in Western Australia, and the upper or *Turritella* beds near Table Cape (6, p. 242; 250), Tasmania, both probably lower Miocene, and the upper beds at Beaumaris (17), Victoria, with a latest occurrence of *Cinnamomum* in probably Upper Miocene strata.

In Western Australia non-marine strata attributable to some part of Tertiary time include the lacustrine clays and basal grits and conglomerates (7), totalling at least 100 feet in thickness, which rest unconformably on the Permo-Carboniferous coal measures of the Collie River, in the South-West Division, and are in turn overlain by gritty laterite.

Of Tertiary age, perhaps Miocene or Oligocene, are lacustrine deposits of numerous areas in Eastern Queensland (2, 20), including those of the Baffle Creek basin near Port Curtis and of Duaringa in the Dawson valley, and the lignites of Water Park Creek, north of Rockhampton.

## Pliocene.

Perhaps referable here are the newer deep leads (27, 195) of S.E. Australia and Tasmania (6), in part covered by the newer volcanic rocks and sometimes containing leaves or fruits, as at Haddon (212, 663) in Victoria, Gulgong (18, 206) in New South Wales, and Brandy Creek (210) in Tasmania. Similar in age may be lacustrine deposits of the Derwent (631, 632) and Launceston (629, 630) basins in Tasmania, while in Victoria the "torrent gravels" of East Gippsland (617, 694) are probably late Pliocene and the result of the initiation of uplift in the Eastern Highlands.

Though the *Planorbis* limestones of Mt. Elder Range (7), in the Kimberley region of Western Australia, have been referred to the Pleistocene (619), their physiographic setting suggests a Pliocene age.

In Central Australia the Arltungan (preferably Arltunga) series (639), perhaps late Tertiary to Pleistocene, consists of sands, clays, and gravels, usually as small mesas, often with chalcedonized "duricrust." The series includes *Planorbis* limestone on Paddy's Hole Plain, and limestones with *Corbicula* on the Hale Plain near Claraville, both in the Arltunga district of the Eastern Macdonell Ranges.

Over much of the interior of the continent silicified or otherwise indurated superficial deposits, which have been termed "duricrust" (705), belong to some part of Tertiary time. Somewhat similar, in Eastern Australia, are the silicified sands or "grey billy" (645) of ancient river deposits, perhaps Pliocene, whose silicification is commonly ascribed to overlying basalt, as at Keilor (108) in Victoria, Tallong, Ulladulla and Moruya (614) in New South Wales, and at Bald Hills in S.E. Queensland, where quartzites occur in the Petrie series (633), chiefly quartzite breccias and micaceous sandstones of late Tertiary age.

Tentatively to the Pliocene have been ascribed some of the deep soils, including "red earths" and "red loams," of Queensland (616), and some of the plateau soils of New South Wales (615) may be similar in age. The older alluvia, sometimes with extinct marsupials, may range back into the late Pliocene, though the majority are more probably Pleistocene.

## Igneous Rocks.

In Eastern Australia an earlier volcanic series, chiefly basic, which is developed in south-central Victoria, in north-western Tasmania, in northern New South Wales, and in south-eastern Queensland, is probably chiefly Oligocene, with some members of Lower Miocene age.

In Victoria the Older Volcanic series ("Older Basalts"), which at Western Port is more than 1,000 feet in thickness, includes (661) olivine-basalts, olivine-titanaugite-basalts, and crinanites, as well as some limburgites and nephelinites, all of which are also represented in the associated dyke-swarms, together with camptonites and other lamprophyric types. The "Older Basalts" are overlain unconformably by marine Barwonian sediments, chiefly Lower Miocene, which include Janjukian limestone at Airey's Inlet (102), Batesfordian limestones at Flinders (23, 137) and Keilor (77, 108), and Balcombian marls at Balcombe Bay (36, p. 30; 111) and Curlewis (76, 105), and ironstones at Royal Park (13, 70, 108, 158). While these basalts are probably Oligocene or even older, the older basalt of Maude (106), resting on Janjukian limestones and unconformably overlain by Balcombian limestones, must be of Lower Miocene age. In South Gippsland the Older Volcanic series underlies the principal lignite seams of the Yallourn series, as at Warragul (36). Yarragon (624, 648), Yallourn (624), and Boolara (648), but occasionally is underlain by thin lignite seams, as at Yarragon (648), rarely thicker, as at Elizabeth Creek, Allambee East (648), and Narracan (652*a*), or by lignitiferous sands as at Balcombe Bay (36).

Perhaps referable to a similar Oligocene horizon are the basalts overlying the older deep leads at Emmaville (18) and elsewhere in the New England district of New South Wales, and the basalts of the Redbank Plains series and interbedded in the Silkstone series (633) of South-eastern Queensland, as well as the basalt of Marrawah, on the west coast of Tasmania, pebbles of which occur in the adjacent Barwonian bryozoan limestone (10, pp. 25, 26, 50).

The relationship of these older volcanic rocks to beds containing the *Cinnamomum* flora is a varied one. In Victoria at Bacchus Marsh (9, 28) the basalt is the older, but at Narracan (644), Dargo (643), and elsewhere the leaf beds are covered by basalt, a relation also obtaining at Vegetable Creek (Emmaville) (18) in New South Wales and at Redbank Plains (633) in Queensland.

Alkaline lavas and intrusive rocks, perhaps chiefly of late Tertiary age, are developed in all States except South Australia. By some authors they have been regarded as constituting a middle series of eruptions intermediate in age between the older and the newer volcanic series, both dominantly basaltic; others have associated the alkaline rocks with one or the other of these main series. Though it is tempting to correlate the alkaline rocks and, indeed, David (2) referred most of them to the Pliocene, in many cases the evidence of age is but slight.

In Western Australia the leucite-lamproites of the Fitzroy River in the West Kimberley district (677, 684) include plugs and fissure intrusions which are post-Permian and may be of Tertiary age.

In S.E. Tasmania the alkaline intrusive rocks of Port Cygnet and Woodbridge (673) are post-Triassic and probably Tertiary. They include alkali-syenite-porphyry, foyaite-porphyry, solvsbergite-porphyry, and tinguaite-porphyry, as well as many other types.

In Victoria alkaline rocks are associated both with the Older Volcanic series (Oligocene to Lower Miocene) and with the Newer Volcanic series (late Pliocene to Pleistocene or possibly Holocene), but chiefly with the latter. To the former have been attributed (656) the phonolite and tinguaite which form pipes and dykes near Harrietville (674) in N.E. Victoria; to the latter belong the alkaline volcanic rocks of the Macedon district (659, 679) in Central Victoria, perhaps in part Upper Pliocene, including solvsbergite, anorthoclase-trachyte, anorthoclase-basalt, oligoclase-basalt (macedonite), woodendite, and limburgite. Trachytes and trachyphonolites or phonolites also occur near Trentham in Central Victoria, near Casterton in South-West and Omeo in North-East Victoria.

In New South Wales alkaline rocks, both extrusive and intrusive, are widespread and have been associated (653) with the older basic series, probably Oligocene to Miocene, but by others have been placed later (2, 681). They include the comendites, trachytes, trachyandesites, and tuffs of the Canobolas Mountains (682) near Orange, the trachytes and phonolites of the Warrumbungle (665) and Nandewar Mountains (666), the comendites and anorthoclase-trachytes of the Lansdowne Plateau (653) near Taree, and the tinguaite laccoliths of the Barigan district (653).

Similar alkaline rocks occur in S.E. Queensland (671), notably the trachytes and tuffs of the Main Range, Fassifern district, and Mount Flinders (669), and the plugs and flows of the Glass House Mountains (664), including pantellerites, comendites, trachytes, and dacite. In Central Queensland the volcanic rocks of Springsure (670) include trachyte, trachyte tuff, and phonolite in their middle portion.

The Newer Volcanic series of south-western and central Victoria, though including Pleistocene and perhaps Recent members, was initiated at a period variously regarded as late (17), middle (663), or early (18) Pliocene or even older (650). The earliest flows in the Western District of Victoria appear, however, always to be post-Kalimnan, though their relation to the Werrikooian is not fully clear. The Drik Drik basalt has been regarded as pre-Werrikooian (18, p. xxii); those of the Portland district, which may be younger, overlie oyster beds (82, p. 230; 84, p. 446) which the writer (159) has correlated, though not on very secure grounds, with those conformably overlying the Werrikooian shell beds of the Glenelg River. In any case the Tertiary members of the Newer Volcanic series can be regarded as not older than Middle Pliocene, at least in South-west Victoria.

Petrographically (659) they are chiefly olivine-labradorite-basalts, but limburgitic and alkaline types occur. Some of the latter have already been mentioned; of the others, in many instances, the age is post-Tertiary.

Probably to be correlated with the Newer Volcanic series of Victoria are the olivine-basalts of Tasmania (660), best represented on the north-west coast, where they overlie marine Janjukian near Table Cape (131). They also overlie the lacustrine deposits of the Launceston Tertiary basin, and may largely be Pliocene.

In New South Wales a newer basic series of lavas and intrusive rocks has been regarded as largely early Pliocene in age (653, 681). Though known as far south as Moruya (21), the lavas are best developed in the northern part of the State, notably in the New England district. They are largely olivine-basalts, but include andesitic basalts with little or no olivine, as well as alkaline types such as nepheline-basalts and leucite-basalts, and also, in the extreme north, acid pitchstones.

In South-east Queensland an upper division of volcanic rocks (669, 671), largely basic, may be Pliocene, at least in part. They are chiefly olivine-basalts, but andesites and andesitic basalts also occur. Beneath the basalts or intercalated with them at the Springbrook Plateau (653, p. 30) are rhyolites and pitchstones which may belong to the same series, though Richards (669) had regarded the acid lavas and agglomerates of the Macpherson Range (653, p. 30; 671, p. 295; 681, p. 44) as contemporaneous with the trachytes elsewhere.

Basaltic rocks occupy large areas in Central and Northern Queensland, but may in part be post-Tertiary (671, p. 298), since volcanic activity appears to have persisted, as in Victoria, up to Recent times.

In contrast to the olivine-basalts of Victoria are the tholeiites (658) of Western Australia, occurring in the extreme south-west in isolated areas from Bunbury to Cape Gosselin (657) and the Donnelly River. Being antecedent to the Coastal Limestone, which is probably Pleistocene, they may provisionally be referred to the Pliocene.

## Diastrophism and Palaeogeography.

Following the recession of the Cretaceous seas, which occupied much of the interior of Australia in Upper Albian time (Tambo series of Queensland and South Australia), and persisted till Santonian and even Campanian time (Cardabia series) in Western Australia (156), the greater part of the continent appears to have been undergoing denudation in early Tertiary time, and marine Eocene deposits are confined, so far as is known, to the extreme north-west and perhaps the south-west.

There is, however, no agreement as to the degree of completion reached by the erosion cycle initiated by the uplift in late Cretaceous or epi-Cretaceous time, which in Queensland was associated with the folding of strata of Albian to Cenomanian age (Burrum and Styx coal-measures). David (2) believed that in Eocene times almost the whole of Australia was a nearly perfect peneplane, while Fenner (689, 690) thought that even in the earliest Eocene the land area might have been very low and level, and in any case by the end of the Oligocene must have developed a high degree of peneplanation, a view accepted by Lewis (690) and by Nye and Blake (10) for Tasmania.

On the other hand, Denmead and Bryan (690) considered that in Eastern Queensland, following a late or epi-Cretaceous orogeny, considerable surface relief (691) was present in Eocene and Oligocene times, instead of a well developed peneplane in the late Oligocene. For New South Wales, Sussmilch (18, 690), and for Victoria, Hills (696), agreed that a Cretaceous peneplane had suffered a late or epi-Cretaceous epeirogenic uplift estimated by the former as 450 to 1,500 feet, and by the latter as more than 2,000 feet. They thus picture tablelands at the commencement of Tertiary time, out of which, according to Sussmilch, an erosion cycle carved by the end of the Miocene a younger or Great East Australian Peneplane, a concept earlier put forward by Andrews (685). Hills (690), however, believed that in Victoria mature dissection of the elevated highland region had occurred by Oligocene times, when the Older Volcanic series was first extruded, but that no well developed peneplane was formed, though flat areas were present notably in the plain tracts of the streams.

In Western Australia, Jutson (690, 700), though allowing the possibility of uplift at the close of the Cretaceous followed by an early Eocene dissection, postulated the reduction of the whole State by post-Cretaceous erosion to a vast plain, probably chiefly by peneplanation, but perhaps marginally by marine abrasion. Since marine Miocene deposits rest on these marginal areas, the planation was regarded as completed by Oligocene or perhaps very early Miocene times.

It is evident that physiographers show a measure of agreement in regard to an early Tertiary erosion cycle following on a probably epi-Cretaceous uplift, but that there is disagreement as to whether this cycle achieved completion by the beginning of the Miocene. It may well be that both views are in some degree correct: that in part, notably in the western half of the Continent, peneplanation was further advanced than elsewhere, while in portions at least of Eastern Australia the more elevated regions had not yet been reduced by erosion. If the older volcanic rocks of South-Eastern Australia are correctly referred to the Oligocene, the topography, though mature, was by no means a peneplane.

If we turn to the evidence of marine sedimentation, we find that the Upper Eocene deposits of North-West Australia and the Upper Cretaceous Carbadia series show marked parallelism of attitude and that both have been folded together (156). But since the highest Cretaceous horizon recorded is probably Campanian, and Paleocene to Middle Eocene beds are as yet unknown, it would appear that the relation is one of disconformity, marking a retreat of the late Cretaceous sea before its readvance in the Upper Eocene (Giralian). Since the date of reading of this paper Spath's recognition of a Maestrichtian fauna (*Journ. Roy. Soc. W. Aust.*, vol. 26, 1940, in press) has been reported by Teichert (703), who regards the Tertiary sequence as conformable to the Cretaceous. The extent of this transgression in the North-West Division of Western Australia remains uncertain, since the evidence of an eastward extension of the Eocene sea to Merlinleigh, 115 miles inland from the present coastline, afforded by the discovery of *Aturia* cf. *ziczac* (569), is vitiated by a doubt as to whether the specimen may not have been transported there by human agency.

The next marine horizon recognized in North-Western Australia is not older than Upper Oligocene, so that there may have been a recession and readvance of the sea in this area. This may also be the period of first marine transgression at the head of the Great Australian Bight, in the Murray basin and along the southern coast of Victoria (Anglesean).

The downwarping which allowed of this was apparently the aftermath of movements of sag (perhaps accompanied at their initiation by volcanic activity), which had permitted the accumulation in Oligocene times of a thick Yallourn series of lignites, sands, and clays in a basin or basins extending in Southern Victoria from the Parwan-Altona area, south-west of Melbourne, easterly past Morwell and the Latrobe Valley nearly to Sale. Whether part of the Yallourn series of non-marine deposits was contemporaneous or penecontemporaneous with the earliest stages of marine transgression (Anglesean ?) in the East Gippsland basin is uncertain, but at all events no thick seams of brown coal are known to overlie marine Barwonian deposits, while the reverse is frequently the case. There is evidence of some oscillation of the Oligocene shoreline, given by deep bores near Lakes Wellington and Victoria (*infra*, p. 81 and fig. 15).

By the beginning of the Miocene, embayments of the Janjukian sea were already well established in South-eastern Australia, notably in the East Gippsland, South Central and South Western areas of Victoria, and in the Murray Gulf which extended from Aldinga in South Australia, across the site of the present Mt. Lofty ranges, into the Mallee district of North-west Victoria (Mount Gnarr bore (57), 754 feet) and into New South Wales (South Ita bore (134), 420 feet), more than 200 miles inland from the present coastline. In North-west Tasmania the littoral "Crassatella" grits, in places conglomeratic, near Table Cape, laid down in the transgressive phase of the Janjukian sea, contain a fauna closely comparable with that of fairly shallow water but not littoral deposits of the type locality near Torquay in Victoria, with which area the sea was doubtless continuous. At Table Cape the overlying Turritella beds (sandy clays) constitute the succeeding shallow water phase of a cycle of sedimentation which is very incomplete. Approximately at the same time a continuance of sagging movements at the head of the Bight resulted in development of what Jutson (700) has termed the Eucla Gulf, nearly to 200 miles north of the present coastline.

Continued sinking, aided by the reduction of relief due to the early Tertiary erosion cycle, resulted in a maximum transgression, in late Lower Miocene and Middle Miocene times (Batesfordian and Balcombian), of seas in which accumulation of limestones was favoured by the reduction of terrigenous material from the diminished and low-lying land areas. In Victoria the chief basins of sedimentation were, as already noted, in East Gippsland from Orbost to Woodside; in South Central and South-Western Victoria, probably continuous beneath the basalt cover of the Western District; and that portion of the Murray Gulf represented by the Wimmera and Mallee districts of North-west Victoria. These three main areas were partially separated by the Palaeozoic or older rocks of Wilson's Promontory and of the Dundas area respectively. Since the deposits of the Murray Gulf are known chiefly from borings, no definite delimitation of its boundaries can be made, but the northern limit is at least as far as lat. 32° 38′ S. (Buckalow bore (134)) and may be set by the ancient rocks of the Barrier Ranges near Broken Hill, while to the east, marine Tertiary deposits are known in New South Wales in long. 142′ 55° E. (Arumpo bore (94)) and borings in Northern Victoria suggest a boundary in approximately the same longitude (697, p. 299). Towards the outlet of the Gulf an upwarp, probably Pleistocene, has caused the Murray River to expose marine Barwonian (in part Balcombian ?) and overlying Kalimnan (?)

strata in cliff sections from near Overland Corner almost to its exit into Lake Alexandrina. Southerly from these sections borings in the Murray Plains (123) suggest that the Murray Gulf continued down to the Mount Gambier district in the south-east of South Australia, and the deposits of this area are probably continuous with those exposed in the cliffs of the lower Glenelg River in South-Western Victoria.

No evidence of Miocene seas is available along the eastern coastline of Australia, since in these regions subsidences in late Tertiary time (2, p. 174) have left the deposits beneath sea-level and inaccessible to observation. In the south-west, however, the occurrence of marine Miocene deposits on the surface of the Western Australian peneplane (?), as far north as Norseman, 120 miles inland, is evidence of a considerable submergence (690, p. 467; 693; 700; 701); while in the north-west submergence in Miocene times, perhaps from slightly earlier than Batesfordian into probably Balcombian times, is indicated by limestones from near North-West Cape southwards to Carnarvon.

Although the Tertiary rocks are commonly either horizontal or very gently tilted, highly dipping and even vertical strata are known where they have become involved in fault movements, as on the coast near Sellick's Hill (698) in South Australia, at Longford (183, p. 210), near Sale, and at Waurn Ponds in Victoria, where Janjukian limestones have been sharply flexed in a very asymmetric syncline with one perpendicular limb. Folding of Janjukian strata has occurred, however, at the type locality near Torquay (183, 686), where a denuded half-dome shows dips of about 10°, and on the Aire coast, where there is gentle folding (110), with dips of 40° off the Jurassic rocks at Castle Cove. The Balcombian clays and limestones of the type locality of Balcombe Bay show dips of up to 20° and slight contortion of strike (111), and those of Grice's Creek much higher dips, which are attributable to landslips or faulting. At Curlewis, however, folding and faulting (23, 76, 105) occur in strata here assigned to the Balcombian, and at Beaumaris (108, p. 190) a monoclinal or asymmetric anticlinal fold, with a maximum dip of about 25°, is developed in strata not older than Upper Miocene (Cheltenhamian). The date of this folding is uncertain, and may be as late as Upper Pliocene.

In Queensland the orogeny in which strata perhaps as young as Cenomanian have been strongly folded, and regarded by some as epi-Cretaceous (690, p. 470), has been claimed to be Tertiary in age (702, p. 306). In any case folding of Tertiary lacustrine deposits, with dips up to 45° at Baffle Creek, appears to be established (702, p. 309).

In the North-west Basin of Western Australia open folding, in which marine beds from Upper Eocene to Miocene are involved, has been referred to the late Miocene or Pliocene (67, 74, 156). The folds trend from 10° to 25° east of north and the anticlinal members, of which the Cape Range, Rough Range, and Giralia Range anticlines are the chief, form topographic ridges more or less dissected by stream erosion. Though dips are low, being from 2° to 8°, the large size of the structures, in the case of the Cape Range anticline 25 miles in width and 100 miles in length, has caused marine Tertiary rocks to be elevated to 1,200 feet above sea level. Since the underlying Upper Cretaceous beds (Cardabia series) are folded with the Tertiary strata, it is believed that no marked structural deformation occurred during early Tertiary time, followed, according to David (2, p. 19) by post-Miocene folding due to easterly directed thrusts from the Indian Ocean.

In South-East Australia sagging movements continued through Upper Oligocene to Middle Miocene time, permitting accumulation of marine marls and limestones, under shallower bathymetric conditions, perhaps 15 to 30 fathoms, than previously (27) suggested, to considerable thicknesses, over 2,500 feet at Lake Kakydra (41, p. 35) near Sale, in the centre of the East Gippsland basin, and over 2,000 feet at Portland (57, p. 401) in South-west Victoria. In the Sorrento bore (63) in the Port Phillip area the corresponding thickness is about half this latter amount, and probably the same is true of the Murray Gulf.

By Upper Miocene times (Cheltenhamian) this downward movement had already been arrested, and may have been reversed, and by the Lower Pliocene the Kalimnan seas were shallower, perhaps 10 to 15 fathoms in depth, and probably considerably restricted in extent, though it is difficult to draw exact boundaries. The dominant lithological types are fine sands and sandy clays, with an absence of pure limestones. Evidence of a break in sedimentation is afforded by slightly phosphatic nodule beds at the base of the Kalimnan at Grange Burn in the Hamilton district, and elsewhere, and at the base of the Cheltenhamian at Beaumaris.

In the Middle Pliocene the grey sands and shelly fauna of the Adelaidean alike suggest shallow water conditions, perhaps 5 or 6 fathoms in depth, but their geographic distribution is limited to the vicinity of Adelaide on the north and west. The fauna is rather closely related to that of the Kalimnan, and though it may perhaps be present in the Sorrento and Mallee bores, the Adelaidean stage has not been recognizable with certainty outside the type area. The filling up of the Murray gulf by clastic sediments may have been accompanied by a draining back of the shallowing sea as a result of initiation of upwarp movements in the later Pliocene. At all events towards the close of the Pliocene definitely marine conditions had disappeared from the greater part of the Murray basin, and Werrikooian seas, in which shallow water and even sub-littoral shell beds and sandy limestones were accumulated, were largely restricted to the extreme south-west of Victoria, adjacent areas in South Australia, and perhaps a former estuary near Tintinara (57, p. 400; 68; 123, p. 185; 179) on the lower Murray plains. The final elevatory movements which drained this Werrikooian sea were post-Tertiary and thus outside the scope of this survey.

There is no unanimity as to the interpretation of the terrestrial record of Miocene and Pliocene times. Woolnough (704, 705) believed the lateritic duricrust of Western Australia was formed during a period, which he regarded as approximately Miocene, of extreme peneplanation, but this conception has been criticized by Clarke (690, p. 467). This surface, which is the "Great Peneplain of Western Australia" of Jutson (700), was thought by him (690, p. 469) to have suffered uplift, commencing in the late Miocene or early Pliocene and interrupted by several intervals of stillstand, during the first of which, in the Pliocene, the wide valleys of the Meckering Level were excavated. Subsequent elevatory movements, probably successive, with warping and some faulting, and chiefly also Pliocene, were thought to have given rise to the present Westralian plateau.

Fenner (688, 689) not only postulated for much of Australia an epi-Miocene gradual uplift, passing in the Pliocene into heavy block faulting and differential uplift, but also tentatively suggested a late Pliocene stillstand with peneplanation in South Australia. While a period of Pliocene stillstand has been supposed for part of Western Australia, as above noted, it was not long enough for peneplanation, though broad valleys were cut. Nor has the hypothesis of late Tertiary peneplanation, though apparently adopted by David (2, p. 91), proved acceptable for Tasmania (690, p. 471) although Lewis (692, p. 401)postulated a late Tertiary peneplain, elevated to 1,400 feet in late Pliocene times, or for Victoria (690, p. 474), where, however, post-Miocene erosion has truncated a fold in Cheltenhamian rocks at Beaumaris.

The period of epeirogenic uplift, with accompanying warping and block-faulting, which initiated the present erosion cycle, was placed at the end of the Pliocene and termed the Kosciusko Period by Andrews (685), who regarded the movement as dislocating a surface with broad shallow valleys. These wide, mature "Upland Valleys" of New South Wales were believed by Sussmilch (18; 690, p. 465) to have been cut during a cycle initiated by an epi-Miocene uplift of the order of 400 feet. There is no general agreement as to whether the period of maximum uplift (Kosciusko epoch) should be regarded as early Pleistocene (685; 689, p. 471) or as late Pliocene (2, 18), which latter is probable in Victoria (695).

## Conclusion.

### Correlation within Australia.

The writer's views on correlation within Australia are summarized in the accompanying table. Since he believes that only the broadest correlations are possible with Tertiary deposits in distant parts of the world, and that while even internal correlations are not yet satisfactorily established, it is impracticable to equate local stages with those of Europe, the reference in the correlation table to subdivisions of the major European units is a tentative one. For this reason the use of a local nomenclature for stages is important, as has been proved in the parallel case of New Zealand, and its partial discontinuance by some Australian authors is to be deplored as a retrogressive step, tending towards that confusion which the local names were designed to reduce.

Should it be proved, as is probable, that stages exist which are not covered by the names already proposed, further stage names should be introduced, provided they are rigorously defined.

### Correlation with the East Indies.

The studies of the larger foraminifera which have already been made enable a provisional correlation with the stratigraphic divisions established by the Dutch geologists in the Netherlands East Indies. Most of this work in Australia has been done by Chapman and by Miss Crespin, whose correlations differ in part from those made elsewhere in this paper and here summarized:—

| Europe. | East Indies. | Australia. |
|---|---|---|
| Miocene | *g* | |
| | *f* | Balcombian marls with *Trillina howchini*. Muddy Creek (Clifton Bank) and Mitchell River (Skinner's), Victoria.<br>Limestone with *Trillina howchini*, *Flosculinella bontangensis*, *Lepidocyclina*, &c. Cape and Rough Ranges, Western Australia.<br>Batesfordian limestones with *Lepidocyclina* cf. *tournoueri* and *L. verbeeki*. Batesford, Keilor, Hamilton bore (Muddy Creek), &c., Victoria. |
| | *e* | Limestone with *Lepidocyclina murrayana*, *L. verbeeki*, &c. North West Cape Range, Western Australia. |
| Oligocene | *d* | Limestone with *Lepidocyclina dilatata*, *L. papuanensis*, &c. North West Cape Range, Western Australia. |
| | *c* | |
| Eocene | *b* | Giralian limestone with *Discocyclina* and *Pellatispira*. Giralia Range, Western Australia. |
| | *a* | |

# TENTATIVE CORRELATION TABLE OF THE TERTIARY ROCKS OF THE COMMONWEALTH OF AUSTRALIA.

| | | Marine Stages. | Western Australia. | | South Australia. | | Victoria. | | Tasmania. | | New South Wales. | | Queensland. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Marine. | Non-Marine. | Marine. | Non-Marine. | Marine. | Non-Marine. | Marine. | Non-Marine. | Marine. | Non-Marine. | Marine. | Non-Marine. |
| Pliocene | Upper | Werrikooian | | ? Laterites developed superficially.<br>Cherts of Mount Elder Range with *Planorbis hardmani*.<br>? Tholeiitic basalt of Bunbury. | ? Tintinara bore. | ? Arltunga series of Central Australia, sands, clays, and gravels, often with "duricrust," and freshwater limestones in Arltunga district, Eastern MacDonnell Ranges. Silicified "duricrust" of the Interior of Australia, in part. | Ostrea limestone of S.W. Victoria, in part. Shell beds of Glenelg River, Moorabool Viaduct, Sorrento and Mallee bores. | Torrent gravels of East Gippsland.<br>? Earliest flows of Newer Volcanic series (basalts, &c.).<br>? Alkaline volcanic rocks of Macedon, in part. | ? Wingaroo bore, Flinders Island. | ? Basalts of North West Coast. | | ? Plateau soils, in part.<br>Newer volcanic series (basalts), in part.<br>Sands, gravels, and "grey billy" of Hunter River Valley, South Coast, &c. | | ? "Red loam" and "red earth" residuals.<br>? Rhyolites and basalts of South East Queensland.<br>? Petrie series of sandstones, quartzite, &c. |
| | Middle | Adelaidean | | ?? Alkaline volcanic plugs of Kimberley Division. | Shelly sands of Dry Creek, Abattoirs, and other bores near Adelaide. | | | Younger "deep leads" with fossil fruits at Haddon, &c. | | Sub-basaltic leads with fossil fruits, Brandy Creek, &c.<br>? Lacustrine beds of Launceston and Derwent Basins. | ? Ferruginous grits of Moruya. | Sub-basaltic leads of Gulgong with fossil fruits. | | |
| | Lower | Kalimnan | | | ? Upper beds of Murray River cliffs and at Aldinga. | | Sands and marls of East Gippsland, Muddy Creek (upper beds), upper part of Sorrento, Mallee and Wimmera bores. | | | | | | | |
| Miocene | Upper | Cheltenhamian | ? Limestone of W. side of North-West Cape Range. | | ? Shell beds in well-sinking at Mindarie. | | Sandy marls of upper beds at Beaumaris.<br>? Middle part of Sorrento bore.<br>?? Shell marls of coastal cliffs near Sherbrook River. | Leaf beds overlying marine Barwonian at Sentinel Rock and (?) Pitfield Plains.<br>Sands, clays, and ironstones with *Cinnamomum* at Bacchus Marsh. | | ?? Alkaline intrusive rocks of Port Cygnet and Woodbridge. | ? Shell beds in well-sinkings at Tareena. | ? Alkaline lavas and plugs of Canoblas, Warrumbungle, and Nandewar Mountains.<br>? Plant beds of Warrumbungle Mountains with *Cinnamomum* in trachytic tuffs.<br>Plant beds of Darling Plains, E. of Broken Hill.<br>Quartzite with *Cinnamomum* at Dalton, near Gunning. | | ? Alkaline plugs of Glass House Mountains and lavas and tuffs of Main Range, Fassifern, Springsure, &c. |
| | Middle | Balcombian (Barwonian System) | Limestone with *Flosculinella* and *Trillina howchini* of Cape and Rough Ranges and Carnarvon bore. | ? Lacustrine clays, sands, and conglomerate of Collie River Valley. | Middle beds of Murray River cliffs near Morgan.<br>? Bryozoan limestone of Mount Gambier. | ? Eyre series, sandstones with plant remains, of Lakes Eyre and Torrens. | Shell marls of Mornington, Muddy Creek (lower beds), Fyansford, Barwon Basin, Gellibrand, Mitchell River, and lower part of Sorrento bore. Limestone of upper beds at Maude. Ironstones of Keilor and Royal Park (lower beds). | | ? Bryozoan limestone near Cape Grim and on Flinders and King Islands. | | | | | |
| | Lower | Batesfordian (Barwonian System) | Limestone with *Lepidocyclina murrayana* and *L. verbeeki* of North-West Cape Range. | | | | Lepidocycline and bryozoan limestones of Batesford, Keilor, Flinders, Muddy Creek bore, and East Gippsland bores. | "Older Basalt" of Maude. | | | | ? Eyre series of West Darling District. | | ? Eyre series of Central basin.<br>? Lacustrine beds of Baffle Creek, Duaringa, &c., and lignite of Waterpark Creek. |
| | | Janjukian (Barwonian System) | Plantagenet beds (siltstones) of Albany and Cape Riche.<br>? Limestone of Lake Cowan district near Norseman.<br>Euela limestone of Great Australian Bight. | | ? Limestones beneath Nullarbor Plains.<br>? Lower beds of Aldinga and in Adelaide bores. | | Shell marls and bryozoan limestones of Torquay. Limestone of Waurn Ponds and Maude (lower beds).<br>? Marls and limestones of Aire coast and clays of Cape Otway. | ? Deep leads with fossil fruits at Hoddle's Creek and Tanjil.<br>?? Upper part of Yallourn series. | "*Crassatella*" and *Turritella* beds of Table Cape. | ? Leaf beds of Macquarie Harbour. | Shell marl of South Ita bore.<br>? Ironstone of Arumpo bore. | | | |
| Oligocene | Upper | Anglesean | Limestone with *Lepidocyclina dilatata* and *L. papuanensis* of North-West Cape Range.<br>? Lower part of limestone in bores on Euela Plateau. | | ? Lower beds of deep bores near Mount Gambier. | Sands and pipeclay with leaves, Maslin's Bay, Aldinga.<br>Lignites and leaf beds of Moorlands. | Carbonaceous sands with *Cyclammina* of Anglesea Cliffs, Torquay bore (110–840 feet), and near base of bores in East Gippsland, Mallee (Tiega bore), and Dartmoor. | ? Yallourn series, lignites, sands, and clays of Morwell and Yallourn.<br>Sands, sandy and ligneous clays beneath marine marls in Balcombe Bay bore; sands, clays, and lignite beneath Balcombian at Altona to Parwan (bores).<br>Lignite and clays of Goon Nure bore, East Gippsland; sands and clays at base of Point Addis, Dartmoor, and Mallee bores.<br>Older Volcanic series (basalts, &c.) of Western Port, South Gippsland, &c.<br>Leaf-beds of Berwick, Narracan, Pascoe Vale, &c.<br>? Deep leads of Stawell and upper Moorabool River. | | Basalt of Marrawah. | | ? Older Volcanic series (basalts) of New England.<br>Vegetable Creek (Emmaville) leads with *Cinnamomum*. | | Silkstone series of S.E. Queensland, shales, sandstones, and *Planorbis* limestone with associated basalt.<br>Redbank Plains series of S.E. Queensland with fish and plant remains near Oxley and Darra.<br>Basalts of Redbank Plains and Cooper's Plains. |
| Eocene | Upper | Giralian | *Discocyclina* limestone of Giralia Range and Cape Cuvier, N.W. Division.<br>? Foraminiferal shales of Perth District, between 120–770 feet in King's Park bore No. 1. | ? Freshwater sands and clays between 780–1,950 feet in King's Park bore No. 2. | | | | | | | | | | |

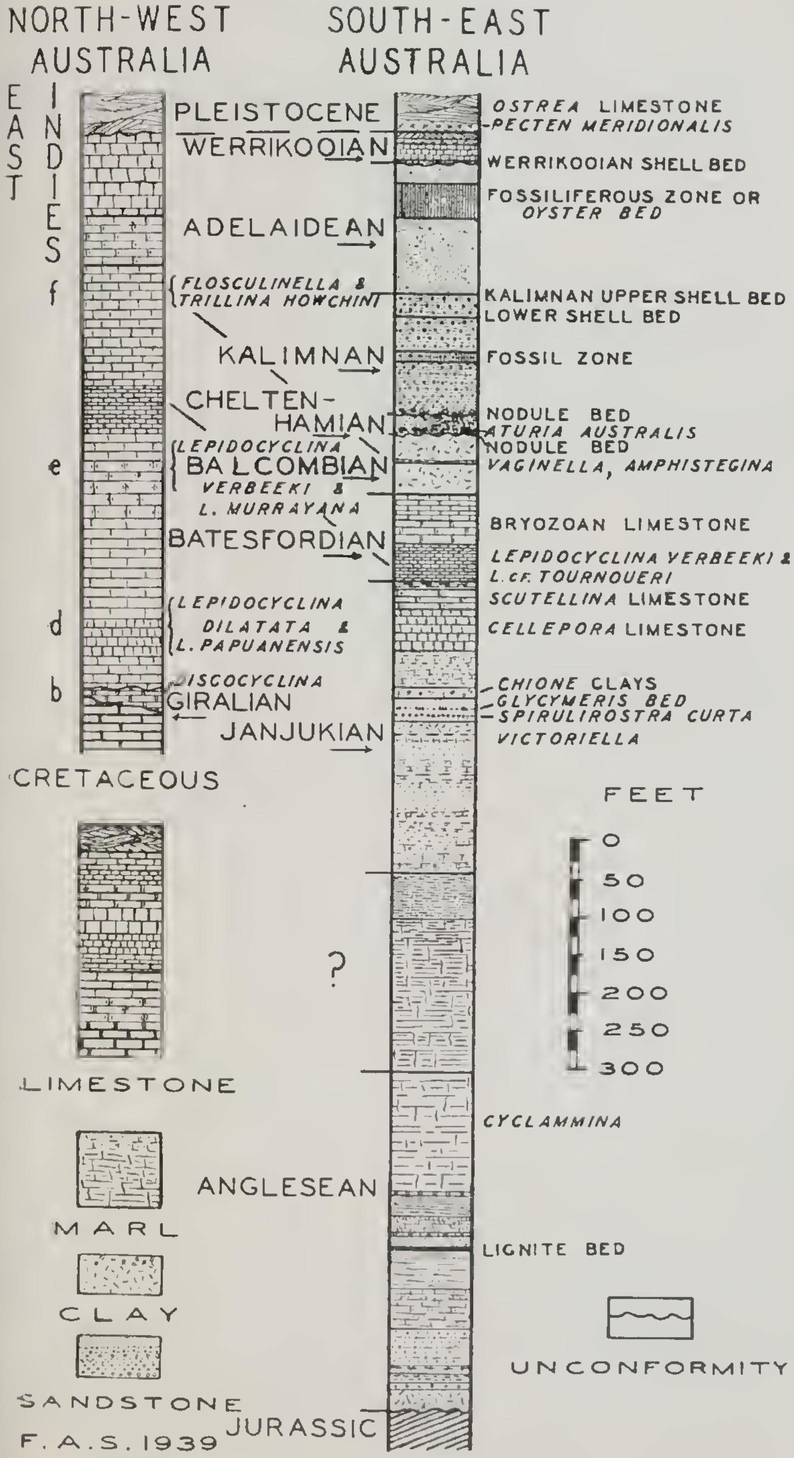



FIG. 11.—Composite sections of the marine Tertiary rocks of North-West and of South-East Australia. Broken lines link equivalent horizons in the two sections.

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## Correlation with New Zealand.

Despite their geographic propinquity, the Tertiary faunas of Australia and New Zealand are notably distinct, at least specifically, and correlation between the two countries is difficult.

At an early date Tate (447) recorded half a dozen species of brachiopods as common to the two countries, but later workers on the New Zealand faunas have accepted (450) only two Australian species. One of these, *Murravia catinuliformis* (Tate), occurs in the *Liothyrella landonensis* fauna, characterizing Allan's Duntroonian stage, regarded by Finlay as the lower member of the Upper Oligocene. The River Murray cliffs (Middle Murravian) constitute the type locality of this species (175), but it has been recorded (275, 543) from localities here referred to Janjukian, Balcombian, and Cheltenhamian stages, a wide range which induced Thomson (450, p. 185) to suggest, probably rightly, that more than one species was included. Until this doubt is resolved the species cannot be utilized for correlation. The other species, *Stethothyris sufflata* (Tate), with Port Vincent on Yorke Peninsula as type locality (543, p. 253), is restricted in Australia to localities (275, 543) belonging to the horizon of Tate's Lower Aldinga series, here referred to the Janjukian. In New Zealand, according to Thomson, it occurs only in the Weka Pass district, ranging from the calcareous mudstone following the main Mount Brown limestone (Hutchinsonian) up to the uppermost Mount Brown limestone (E). It may be noted that Marwick has placed the Hutchinsonian stage as Upper Oligocene, and more recently Finlay (321) as Lower Miocene, while the writer regards the Australian localities as Oligo-Miocene.

The molluscan species supposed identical in the two countries have been listed by Finlay (485), but those critically examined by Marwick (501) proved in all but one case to be represented by allied rather than by conspecific forms, and the same applies to many other records, such as that of the Neozelanic "*Drillia*" *wanganuiensis* Hutton in the type Kalimnan fauna. The exception is *Typhis maccoyi* T. Woods, with which Tate (538) regarded the Neozelanic *Typhis hebetatus* Hutton as synonymous, a conclusion concurred in by Marwick (501). The type locality of the former is Table Cape, Tasmania, to be correlated with the type Janjukian locality of Spring Creek, near Torquay, Victoria, where it is common in the lower sandy marls at the level of Bird Rock, but the species ranges into the Balcombian stage at Muddy Creek, Gellibrand River, and other Victorian localities, though it has not been recorded from Balcombe Bay itself, as remarked by Pritchard (111, p. 48, footnote). In New Zealand it occurs in the Mount Harris beds which are referable to the Awamoan stage recently regarded by Finlay (321) as Middle Miocene, but previously by Marwick as Lower Miocene. Thus it is comparable in age to the range in Australia, in the writer's view from Lower Miocene or Oligo-Miocene to Middle Miocene.

While generic identities in the Mollusca are seldom of much value except for the broadest correlation, a notable exception is that of the Kalimnan *Heligmope dennanti* Tate (540, p. 329) and the Waitotaran *Turbo postulatus* Bartrum, believed to be congeneric by Finlay (488), since his suggestion that *Heligmope* is Ianthinid and thus a pelagic genus is supported by examination of the protoconch of the Australian species. In a second case, that of *Notovola*, this subgenus of *Pecten* had already reached New Zealand by Castlecliffian times, but not Australia until after the end of the Werrikooian, if the definition of this latter stage herein proposed be adopted.

The evidence of other groups is indecisive save perhaps for the Foraminifera. Here the foraminiferal faunule described by Chapman from near Mount Oxford, South Island of New Zealand, contains *Discocyclina* and *Asterocyclina*, an assemblage recalling that from the Giralian stage in North West Australia, but having in addition *Assilina*, relegating it to stage *a* of the East Indian sequence, regarded as Middle Eocene. Finlay (321) has referred the New Zealand occurrence to the Bortonian stage.

The same author (321, 322) has suggested a correlation of the Australian Janjukian with the Waitemata beds (Hutchinsonian) based on his identification from Torquay, the type Janjukian locality, of *Calcarina mackayi* (Karrer), a species restricted in New Zealand to the Waitemata beds (Hutchinsonian). Finlay also records it from Whakau stream, Poverty Bay, with abundant *Nephrolepidina* and *Miogypsina*. This orbitoid-bearing horizon is rather to be correlated with the Australian Batesfordian as herein defined, than with the Janjukian as supposed by Finlay, doubtless owing to Chapman's reference, from which the writer dissents, of the Batesford limestones to the Janjukian.

Attention may also be drawn to *Miogypsinoides dehaarti nitidula* Chapman, which has been recorded by that author (65) from Quobba Cliffs, North West Australia (fig. 1) and also from limestones in the Mount Somers district, New Zealand, which are referred to the Hutchinsonian (Speight, 1938, *N.Z. Geol. Mem.* 3).

A tentative, and probably premature, correlation of the Australian Tertiary stages with those of New Zealand, as set out by Finlay (321), is as follows:—

| | | New Zealand. (Finlay, 1939.) | Australia. (Singleton, 1939.) |
|---|---|---|---|
| Pliocene | U | Castlecliffian | Werrikooian (? new stage) |
| | M | Nukumaruian | Adelaidean |
| | L | Waitotaran<br>Opo'tian | Kalimnan |
| Miocene | U | Taranakian | Cheltenhamian |
| | M | Awamoan | Balcombian } Barwonian |
| | | | Batesfordian } Barwonian |
| | L | Hutchinsonian | Janjukian } Barwonian |
| Oligocene | U | Waitakian<br>Duntroonian | (? new stage)<br>Anglesean |
| | M | Whaingaroan } Ototaran | (? new stages) |
| | L | Kaiatan } Ototaran | |
| Eocene | U | Tahuian } Waimatean | Giralian |
| | M | Bortonian } Waimatean | |
| | L | | |

[Addendum: Allan (443) in a paper bearing the date 9th April, 1940, has described as a new species *Stethothyris epsilon*, the New Zealand brachiopod hitherto identified as the Australian *S. sufflata* (Tate), which latter is transferred to a new genus *Victorithyris*, the two species being homoeomorphs. He has also identified from the Upper Janjukian limestone of "Rocky Point, mouth of Spring Creek, Torquay, Victoria" (443, p. 285) the Neozelanic *Neobouchardia minima* (Thomson), originally described from the main Mount Brown limestone (Hutchinsonian), but ranging downward to the Duntroonian. It may be noted that Allan's "Rocky Point" is local usage for the point immediately south of the mouth of Spring Creek, shown on the military map and in fig. 7 as Jan Juc and to be identified with Pritchard's "Scutellina Limestones" (155). In 1936 Allan did not visit the true Rocky Point (locally also known as Pride's Leap) of fig. 7, the military map and the usage of Tate and Dennant (183, p. 209) and of Hall and Pritchard (107, p. 156). F.A.S., 29.4.40.]

## Discussion of Sequence.

In Section III., the writer has attempted to summarize the views of other writers and in Section IV. his own views on the vexed problems of the sequence and correlation of the Australian marine Tertiary deposits. There remains the necessity to indicate the evidence on which these latter views are based and wherein they may be opposed to those of other workers: such evidence can be here presented only in outline.

*The Relation between Anglesean and Janjukian.*

In 1910, Hall (102) noted that the black sandstone or sandy clays of the cliffs north-east of the Anglesea River seemed to show a gentle anticline, but attributed it to the effect of weathering following the contour of the ground. He concluded that these black sandy beds were apparently the equivalents of the rich marine beds of Spring Creek, or in other words that the Anglesean and Janjukian were different marine facies of approximately the same age.

Nevertheless, the writer believes the anticlinal structure (see Pl. I. fig. 1) to be real, and evidenced on the westerly limb by the dip of the junction between the black sandstone and overlying white sands (*supra*, p. 25), although the fold axis may not trend in the direction shown by Coulson (686. fig. 1). To the east between the Black Rocks and Point Addis there is a gap in the coastal section, occupied by sand dunes which thus mask the relation between the Anglesean black sandy beds and the probably Janjukian limestones of Point Addis, though it must be admitted that the latter dip towards instead of away from the Demon's Bluff section. Since, however, gentle folding of the Tertiary strata between Torquay and Anglesea is present, this dip, which is also shown by the erosion surface (44) within the limestones on the west side of Point Addis, probably lacks stratigraphical significance. Of more importance is the evidence of the borings for oil made by the Point Addis Company at Point Addis (37, p. 21), but, although the bore logs are available (38, pp. 17, 18), this is not the case with the cores themselves, which remain undescribed, so that their interpretation remains doubtful. The same applies in a measure to the bores (37; 38, pp. 15-17) put down by the Torquay Oil Wells Company near the Janjukian type locality south-west of Torquay (Fig. 8), though the general sequence has been stated by Chapman and Singleton (27, p. 996, and *supra*, p. 39) and the bore logs (38) have been utilized in the preparation of the composite section in fig. 11, which suggests a possible intervening stage. In the deeper portions of these bores in the Parish of Jan Juc the richly fossiliferous Janjukian beds are underlain by strata probably referable to the Anglesean, which in some cases contain *Cyclammina* and are often lignitiferous towards the base.

This sequence of these stages is supported by the evidence of borings in the Mallee, Dartmoor and East Gippsland districts in the north-west, south-west, and south-east of Victoria respectively.

*The Relation between Janjukian and Balcombian.*

This, the most controversial topic in Australian Tertiary stratigraphy, requires separate treatment, even though the writer believes it desirable to recognize the Batesfordian as an intermediate stage. It will be apparent from Section III. that Tate and Dennant, though reversing Hall and Pritchard's sequence, here adopted, of the above stages, nevertheless placed the Lower Aldinga beds, here correlated with the Janjukian, at the base of their sequence and hence in an infra-Balcombian position. Although Chapman, the other principal protagonist of the post-Balcombian age of the Janjukian, appears recently to have greatly modified this view (*supra*, p. 11), it is necessary to examine the arguments he has advanced in support of it (23).

Hall and Pritchard relied largely, as does the writer, on the sequence displayed in the valley of the Moorabool River between Maude and Fyansford (map 2; figs. 5 and 12). Their view is based chiefly on the correlation of the lower Maude limestones with the Janjukian and of the Upper Maude limestones, separated from them by the intervening Older Basalt, with the Balcombian, though the local nomenclature had not been instituted at the time of their paper (106). While the lower Maude mollusca include several species apparently restricted to the locality, many of the most characteristic, such as *Eotrigonia intersitans* (Tate) and *Eucrassatella maudensis* (Pritchard), also occur at Torquay, and the correlation with the Janjukian, though unacceptable to Tate and Dennant (185, p. 138) appears justified. The reference of the upper Maude beds to the Balcombian is less well established, though the writer believes them to represent a littoral facies of the Fyansford clays, whose Balcombian age is discussed below. Although detailed mapping of the lower Moorabool valley is desirable, Hall and Pritchard (104, 106, 109) have already shown that the generally downstream dip of the Tertiary rocks results in the disappearance below river level first of the lower Maude beds, followed by that of the Older Basalt, about half way between Bannockburn and the Sutherland's Creek Junction. Downstream from this locality the southerly equivalent of the upper Maude beds is represented by the Batesford bryozoan and lepidocycline limestones (Batesfordian) and the Fyansford clays (Balcombian), which overlie them in turn above Griffin's (fig. 5).

Since the reference of the lower Maude beds to the Janjukian and the general stratigraphical sequence have not been challenged by Chapman, it is evident that the crucial point lies in the age of the clays at Orphanage Hill, Fyansford, which nearly all workers, including McCoy, correlated with those of Balcombe Bay. In 1911 Chapman (455, p. 421) had himself referred the Orphanage Hill locality to the Balcombian, but three years later (23, p. 39) thought its affinities were rather with the Janjukian,

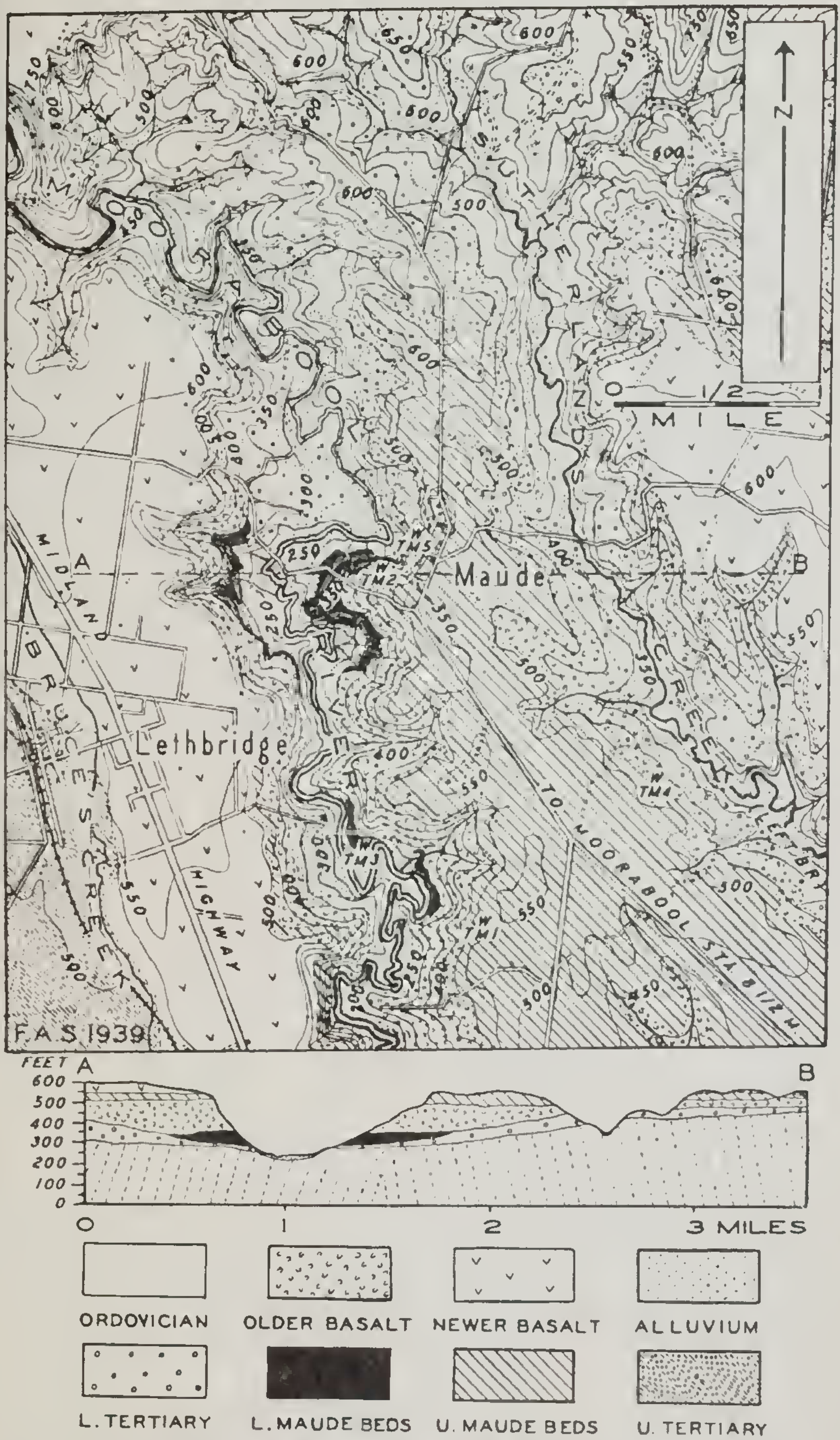


FIG. 12.—Geological map and section of Maude district, Victoria. Geology from Quarter-sheet No. 19 S.W., Geological Survey of Victoria, 1865, with emendations and additions. Contours from Meredith sheet, Military Survey of Australia, 1936.

on the evidence of five of the species recorded by Hall and Pritchard (104), asserted by Chapman to be restricted Janjukian fossils.

The first, *Terebratula vitreoides* T. Woods, although later listed by Crespin and Chapman (450) from Fyansford as a new record, probably refers rather to *T. tateana* T. Woods (cf. 543, p. 251), which is a *Liothyrella* apparently ranging throughout the Barwonian. The next two, *Natica gibbosa* Hutton and *Pleurotoma haasti* Hutton, are almost certainly wrongly identified with those Neozelanic species. In any case the former has not been recorded from the type Janjukian locality or any other whose correlation with it is undisputed, while the latter was deleted by Hall from his own reference copy of Hall and Pritchard's paper (104) and has been omitted from Dennant and Kitson's catalogue (275). Nor do the last two names cited by Chapman, *Limopsis insolita* (Sowerby) and *Cardita gracilicostata* T. Woods, fare any better. The former was not, in fact, listed by Hall and Pritchard, and has since been shown by the writer (525) to differ from Sowerby's species and has been named *Limopsis chapmani* Singleton, a characteristic Janjukian species. But the Fyansford shells prove to be not "*insolita*" (i.e., *chapmani*) but slightly decorticated examples of *L. morningtonensis* Pritchard, which is a species characteristic not of the Janjukian but of the Balcombian.

An Orphanage Hill shell identified by T. S. Hall as *Cardita gracilicostata* T. Woods, is very much smaller than and almost certainly not conspecific with topotypes from Table Cape of *Venericardia gracilicostata* (T. Woods).

Thus it is seen that none of the five species listed can be claimed as a restricted Janjukian fossil and actually none, save for the erroneously identified *Limopsis* "*insolita*," is recorded from the type locality of the Janjukian by Dennant and Kitson (275). This is significant in that Chapman appears to have regarded as a restricted Janjukian fossil one which is present in beds which he correlates with the Janjukian, such as those in the Barwon-Lower Moorabool basin (referred by Hall and Pritchard to the Balcombian), whether or not it occurs at Spring Creek, Torquay, the type locality of the Janjukian (cf. 57, p. 385, of the Mallee bores fauna: "*Gypsina howchini*, Chapm. A restricted Janjukian fossil, known previously only from Batesford.") This is clearly inadmissable, and species supposed restricted to a stage should either occur at the type locality of that stage or at least only at localities whose correlation with the type locality is undisputed.

On the above criteria a much longer list can be made of restricted or characteristic Balcombian molluscan species in the Fyansford fauna, including *Limopsis morningtonensis* Pritchard, *Eucrassatella dennanti* (Tate), *Cerithium apheles* T. Woods, *Umbilia eximia maccoyi* Schilder, *Gigantocypraea gigas* (McCoy), *Austrotriton textilis* (Tate), *Chicoreus lophoessus* (Tate), *Dennantia ino* (T. Woods), *Pterospira hannafordi* (McCoy), *Volutospina antiscalaris* (McCoy), *Conus ligatus* Tate, *Vaginella eligmostoma* Tate.

The Fyansford fauna, then, like that of Murgheboluc, Inverleigh, and other localities in the Barwon River basin, is in actual fact Balcombian and not, as claimed by Chapman, an argillaceous facies of the Janjukian, with a supposed persistence of Balcombian species owing to uniformity of conditions. Argillaceous horizons are well developed in the type Janjukian section, but contain faunas with marked differences from those of Fyansford and Balcombe Bay.

*Hamilton District.*—In a valuable account of this area Chapman (23) referred the lepidocycline and polyzoal limestone of the Grange Burn, like that of Batesford with which he justifiably correlated it, to the Janjukian, and placed it between the Balcombian of Clifton Bank and the Kalimnan of MacDonald's and Forsyth's. But the Batesfordian limestones at the junction of Muddy Creek and Grange Burn rest directly, as reported by Dennant (83), upon the surface of Palaeozoic quartz porphyry, so that if the Balcombian marls were in an inferior position their absence here could only be attributed to overlap by the limestones. The Hamilton bore (Parish of Yulecart, No. 1) on Muddy Creek, which started on the horizon of Clifton Bank and about 50 chains downstream, penetrated lepidocycline limestones (311, p. 5) which incontestably are the older. The Lepidocyclinae, since the record of *Spiroclypeus* (305) has been shown (311, p. 11) to be erroneous, indicate a Batesford horizon, and true Janjukian strata do not outcrop in the Hamilton area.

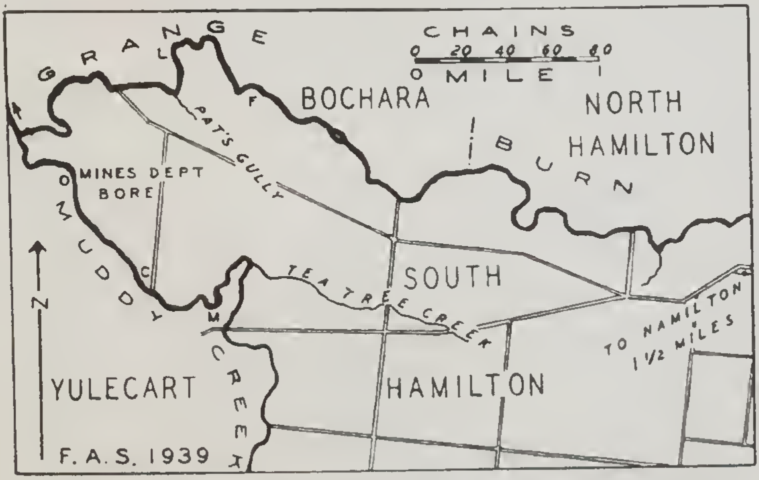


FIG. 13.- Map of Muddy Creek district, near Hamilton, Western Victoria. C. Clifton Bank (Balcombian), F. Forsyth's Bank (Kalimnan), M. MacDonald's Bank (Kalimnan), L. Lepidocycline limestone (Batesfordian).

*Sorrento Bore.*—While Chapman (63) has correctly referred to the Balcombian the lower horizons of this bore, down to its base at 1,696 feet, his reference of the overlying strata between 758 and 1,295 feet to the Janjukian is based on very inadequate evidence. He ascribed the absence of Lepidocyclinae in the bore to deeper water conditions, but it seems more probable that if the bore were deepened the Batesfordian lepidocycline beds would be penetrated, and possibly also the Janjukian.

*Aire Coast* (50, 110).—The basal beds at Wilkinson's No. 5 locality or Castle Cove (fig. 14), which dip at about 40° south-easterly off the Jurassic bedrock, consist chiefly of hard ragged limestones whose fauna recalls that of the Lower Aldinga beds in South Australia. Overlying them are grey marly limestones with *Limopsis chapmani* Singleton, a characteristic species of the lower Janjukian at the type locality and also at Aldinga. At Wilkinson's No. 1 locality, Point Flinders, near Cape Otway, black clays contain a rich molluscan fauna (184), referable to the Janjukian, in which the Lower Aldinga facies is prominent.

At Wilkinson's No. 4 locality a Janjukian shelly fauna occurs in grey sandy clays interbedded in a series of clays and bryozoan limestones also dipping south-easterly but at about 20°. At Wilkinson's No. 3 locality, between Nos. 4 and 5, but separated from them by Pleistocene dune limestones, bryozoan limestones, apparently also referable to the Janjukian, dip north-westerly at a little more than 10°.

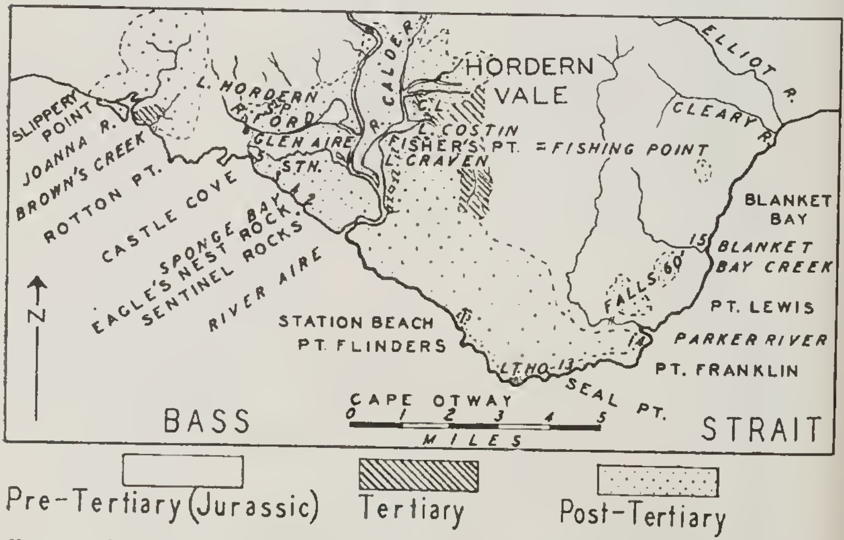


FIG. 14.—Geological map of Aire District, near Cape Otway, Victoria. Modified from maps by Wilkinson, 1865 (50), Krausé, 1874 (34), and Hall and Pritchard, 1899 (110). C.L., Calder limestones. LT., Lighthouse. S.P., Spud Point. Figures refer to localities numbered by Wilkinson.

About a mile inland from these coastal sections (fig. 14), and separated from them by Pleistocene dune limestones and Recent sand dunes, practically horizontal clays and soft bryozoan limestones outcrop on the left bank of the Calder River from Fisher's Point (or Fischer's Point; Fishing Point of Hall and Pritchard (110) and of Dennant and Kitson (275)) southward. The molluscan fauna (110) of Fisher's Point is clearly Balcombian, though the abundance of *Amphistegina* near the top of the section suggests a horizon similar to that of Clifton Bank, Muddy Creek, where this genus is abundant, and probably slightly older than that of Balcombe Bay, where it is wanting.

Though there is as yet no stratigraphic proof of sequence, it is suggestive, as pointed out by Hall and Pritchard (110, p. 54) that the Janjukian strata of the coastal sections show relatively high dips, due apparently to folding, whereas the Balcombian strata, a short distance inland, remain sensibly horizontal. This may indicate an unconformity between Janjukian and Balcombian beds, for Batesfordian rocks are unknown in this area, though probably the Anglesean stage is represented by the dark clays with *Cyclammina* of Brown's Creek (26, 297).

*Mallee Bores.*—Though Chapman (23, p. 49; 57, p. 380) has claimed the borings in the Victorian Mallee show a gradual passage from Janjukian to Kalimnan, it is probable the pre-Kalimnan beds are instead largely Balcombian, since the important restricted foraminiferal species *Trillina howchini* Schlumberger, first described from Clifton Bank, is recorded from several of these bores (57, pp. 335, 338, 339, 360) and others in the Mallee (311, p. 6).

### *The Relation between Janjukian and Batesfordian.*

No exposed section is as yet known where this may be demonstrated and reliance must be placed on the relation above discussed between Janjukian and Balcombian, together with the conformable relations dealt with hereunder between Batesfordian and Balcombian.

It is possible, however, that the missing evidence may be supplied by the stratigraphy of the East Gippsland basin (fig. 15), of which numerous bore cores are being investigated. In this area the Batesfordian stage is represented by marly bryozoan limestones with *Lepidocyclina*, which comprise zones B2 and B3 of Chapman and Crespin (25). These authors record them, as Lower Miocene, in the Metung bore (Parish of Bumberrah, No. 1) between 700 and 873 feet, in the Jemmy's Point bore (Parish of Colquhoun, No. 1, or Lakes Entrance, No. 3) between 770 and 840 feet, and in the Rigby Island bore from 685 to 890 feet. This latter, which is Chapman and Crespin's Kalimna bore (26, pp. 118-120) is also known as Lakes Entrance, No. 4, or Kalimna, No. 1. On a lower horizon is their A2 zone, regarded by them as Upper Oligocene and represented by micaceous foraminiferal marls underlain by glauconitic sandstone. From the micaceous series Chapman and Crespin (25, pp. 6, 7; 26, p. 119) record as restricted foraminifera *Cyclammina incisa* (Stache); *Vaginulina gippslandica* Chapman and Crespin, *Lamarckina glencoensis* Ch. and Cr., and *Victoriella plecte* (Chapman). The last named (267, p. 320; 303) is a restricted species of the lower Janjukian of the type locality, below the summit of Bird Rock, where it is also associated with *Cyclammina*. The micaceous series, occurring in the above mentioned bores at 1,115–1,370, 1,100–1,331, and 1,160–1,385 feet respectively, may therefore be referred tentatively to the Janjukian stage, as may also the underlying glauconitic bed, at 1,396–1,432, 1,331–1,396, and 1,387–1,410 feet respectively, since the writer has provisionally determined therefrom *Turritella* (*Colpospira*) *aldingae* Tate. It may be noted that discrepancies between the above figures and those given by Chapman and Crespin (25, p. 13) are due to supersession of the latter by those of the Boring Records 1923-30 (38, pp. 24 and 89).

### *The Relation between Batesfordian and Balcombian.*

Since these are represented at their respective type localities by strata of contrasted lithology, it might be questioned whether the faunal differences between them may not be due only to differences in facies.

Nevertheless, a conformable succession of Batesfordian by Balcombian strata is demonstrable along the Lower Moorabool River between Batesford and Fyansford (*supra*, pp. 31, 70, and fig. 5) while their superposition was shown beyond doubt by the sections exposed during construction of the tunnel to the new quarry of Australian Cement Ltd. near Batesford.

The Hamilton bore (Parish of Yulecart, No. 1; 38, p. 88) on Muddy Creek (fig. 13), which started near and just below the level of the Balcombian of Clifton Bank, penetrated Batesfordian strata with abundant Lepidocyclinae from 10 feet down to 230 feet (305; 311, p. 5).

At Keilor (77, 108) fossiliferous ironstones, which the writer agrees with Hall and Pritchard in regarding as a littoral facies (108, 155) of the Balcombian, overlie a small exposure of Batesfordian lepidocycline limestone.

At Maude the upper limestones are divisible, as first noted by Tate and Dennant (185, p. 138), into a hard limestone with littoral shells, probably a facies of the Balcombian, and an underlying softer bryozoan limestone. This latter resembles in lithology and fossils part of the Batesford limestones, though *Lepidocyclina* is not yet known to occur.

Since in the first three of the above areas a Batesfordian lepidocycline limestone is succeeded by fossiliferous beds which are definitely or tentatively referable to the Balcombian, there is strong presumptive evidence for the view that these are distinct but consecutive stages, rather than contemporaneous facies.

Only at Skinner's (91), on the Mitchell River near Bairnsdale, are Lepidocyclinae (311) associated with *Trillina howchini* and with a molluscan fauna of Balcombian affinities. Whether this represents an argillaceous facies of the Batesfordian with its shelly fauna is not yet clear.

### *The Relation between Balcombian and Cheltenhamian.*

This is demonstrated at Beaumaris, the Cheltenhamian type locality (*supra*, p. 32), where the stratigraphic break occurs at the base of a "nodule bed." The underlying Balcombian strata are marls with concretionary limestones which give rise to white pebbles in the shingle. They thus resemble lithologically the beds of Balcombe Bay and Grice's Creek, and are not littoral deposits as stated by Chapman and Crespin (26, p. 122).

At Balcombe Bay (*supra*, p. 27) and at a small gully immediately south of Manyung Rocks, on the coast about a third of a mile south of Grice's Creek, a series of ferruginous sands and grits rests with an even junction upon the fossiliferous Balcombian marls. This ferruginous series is apparently barren at these localities, but at Landslip Point (23, 111) near Frankston, a band containing fossil moulds and casts occurs apparently in the same series. Chapman (23, p. 29; 59) has sought to show that they are referable to the Janjukian, but two of the forms on which he relied are not definitely identified, being listed by him as *Terebratula* (?) *aldingae* Tate and *Pecten* cf. *flindersi* Tate.

Though the type locality of the third, *Pecten praecursor* Chapman, said to be "a specially characteristic Janjukian form" is Spring Creek, Torquay, Chapman cites records from localities such as Shelford, Lower Moorabool and Curlewis-Belmont, whose reference to the Balcombian by Hall and Pritchard (112) is supported by the writer. There is thus little to set against the close resemblance of the rest of the fauna (111) to the Balcombian, and these ferruginous beds, at least in their older part, constitute an immediately post-Balcombian series which may represent wholly or in part the disconformity between Balcombian and Cheltenhamian at Beaumaris.

### *The Relations of the Cheltenhamian.*

The molluscan fauna at the type locality shows an association in a single stratum, about 2 feet above the nodule bed, of Kalimnan species with a subordinate but well-marked Barwonian element. Similarity of preservation precludes a remanié origin for the latter, which, indeed, had induced Tate (181) to correlate these beds with those of Spring Creek, the type locality of the Janjukian stage. That the Cheltenhamian is post-Balcombian is shown by superposition at Beaumaris (*supra*, p. 32); that it is post-Batesfordian by the discovery by W. J. Parr (personal communication) in the nodule bed and immediately overlying strata of worn and glauconite-filled remanié Lepidocyclinae.

While direct superposition of Kalimnan upon Cheltenhamian strata is not definitely demonstrable, the inferior position of the Cheltenhamian is established on palaeontological grounds. It is even possible that the upper ferruginous sandstone (*c*) of the Beaumaris cliff sections (*supra*, p. 33) may ultimately prove to be Kalimnan and the overlying white sands (*d*), like similar beds throughout the south-eastern suburbs of Melbourne, are probably younger still, perhaps Middle or Upper Pliocene or even, as above suggested, Pleistocene.

*The Relations of the Kalimnan.*

At the type locality, Jemmy's Point, Kalimna, deep borings show the Kalimnan strata to rest apparently conformably, or at all events without a basal nodule bed, upon a thick calcareo-argillaceous series which in its upper part is presumably of late Barwonian age. Similar relations obtain in many other borings in East Gippsland and also in the Mallee. At Royal Park (108, 158) near Melbourne ferruginous (hematitic) beds, here regarded as Balcombian, are overlain by limonitic beds with a scant fauna which may be Kalimnan. There is no visible unconformity, but a concealed disconformity may be present.

Elsewhere, as at Muddy Creek and Grange Burn, near Hamilton, the typically Kalimnan beds of MacDonald's and Forsyth's are separated from the underlying Balcombian by a thin nodule bed marking a stratigraphic break. The relation of the Kalimnan to succeeding beds is obscure, but it may be noted that many of the beds referred to the Kalimnan in the Melbourne district may equally well be post-Kalimnan.

*The Relations of the Adelaidean.*

Since beds of this stage are known definitely only from borings, stratigraphical evidence is limited. Nevertheless, the shelly fauna of the Adelaidean shows a marked Kalimnan relationship, so that the two were correlated by Mrs. Ludbrook (140) and some earlier authors (27, 112). The Adelaidean fauna contains, however, at least twice the percentage of living species and it is probably post-Kalimnan (44, 126, 177, 275), a position perhaps supported by the evidence of the Abattoirs bore (fig. 3).

On the other hand, there is sufficient difference between the Adelaidean and Werrikooian faunas to suggest a possible intervening stage yet to be recognized, and Howchin's equation (5) of the two stages cannot be justified.

### *The Relation between Werrikooian and Pleistocene.*

Whether the Werrikooian should be included in the Tertiary or in the Pleistocene has long been the subject of debate. Originally these beds were regarded by Dennant (82, 84) as Pleistocene; then by Tate and Dennant (183) as Newer Pliocene; by Tate (144, p. 84) as Older Pleistocene; by Hall and Pritchard (112) as Pliocene; and by Dennant and Kitson (275), Chapman (22, 23), Chapman and Singleton (27), Chapman and Crespin (26), and the writer (17, 44) as Upper Pliocene. The changes of view by Tate and by Dennant were due to varying opinions as to whether or not most of the extinct molluscan species were of extraneous origin. The writer (43, p. 983) has shown that many of these are in actual fact derived from outcrops of Barwonian clays along the Glenelg River, washed out specimens from both horizons having been indiscriminately collected, and therefore suggested that the Werrikooian might have to be removed to the Pleistocene as advocated by Tate. Nevertheless, a critical study has shown that about 5 per cent. of the mollusca are extinct species, so that the Werrikooian may be placed as Uppermost Pliocene (159), immediately preceding the Pleistocene with a molluscan fauna of living species only.

The stratigraphic succession supports this view (*supra*, p. 47), but if the Pleistocene be marked by *Pecten (Notovola) meridionalis* Tate, then the Dartmoor oyster bed (*supra*, p. 48) must be referred to the Pleistocene rather than to the Werrikooian as done by Chapman and Crespin (26, p. 124).

### *The Relations of the Yallourn Series.*

Since at the type locality marine Tertiary formations are absent, the difficulty arises that where relations between marine and non-marine strata obtain, the correlation of the latter with the Yallourn series may be unjustified. Indeed, this objection has been raised by Sussmilch (18, p. xv) to the writer's correlation (17) of the Yallourn lignites with the much thinner lignites underlying marine strata further to the east (*supra*, p. 50). It must be conceded that the attenuated non-marine strata beneath the marine Barwonian of the western part of the East Gippsland Tertiary basin are not equivalent to the whole thickness of the Yallourn series. Thus far Sussmilch's criticisms may be accepted, but not his claim that the upper part of the Yallourn lignites, with plant remains, might be as young as Lower Pliocene.

The thickness of the Yallourn series at Morweil was asserted by Sussmilch (18) to be comparable with that of the marine strata of East Gippsland, but the latter reaches 2,588 feet at the Lake Kakydra bore (Parish of Nuntin, No. 2) near Sale (41, pp. 30, 35), which also passed through 455 feet of lignite seams and non-marine sediments interbedded with marine horizons

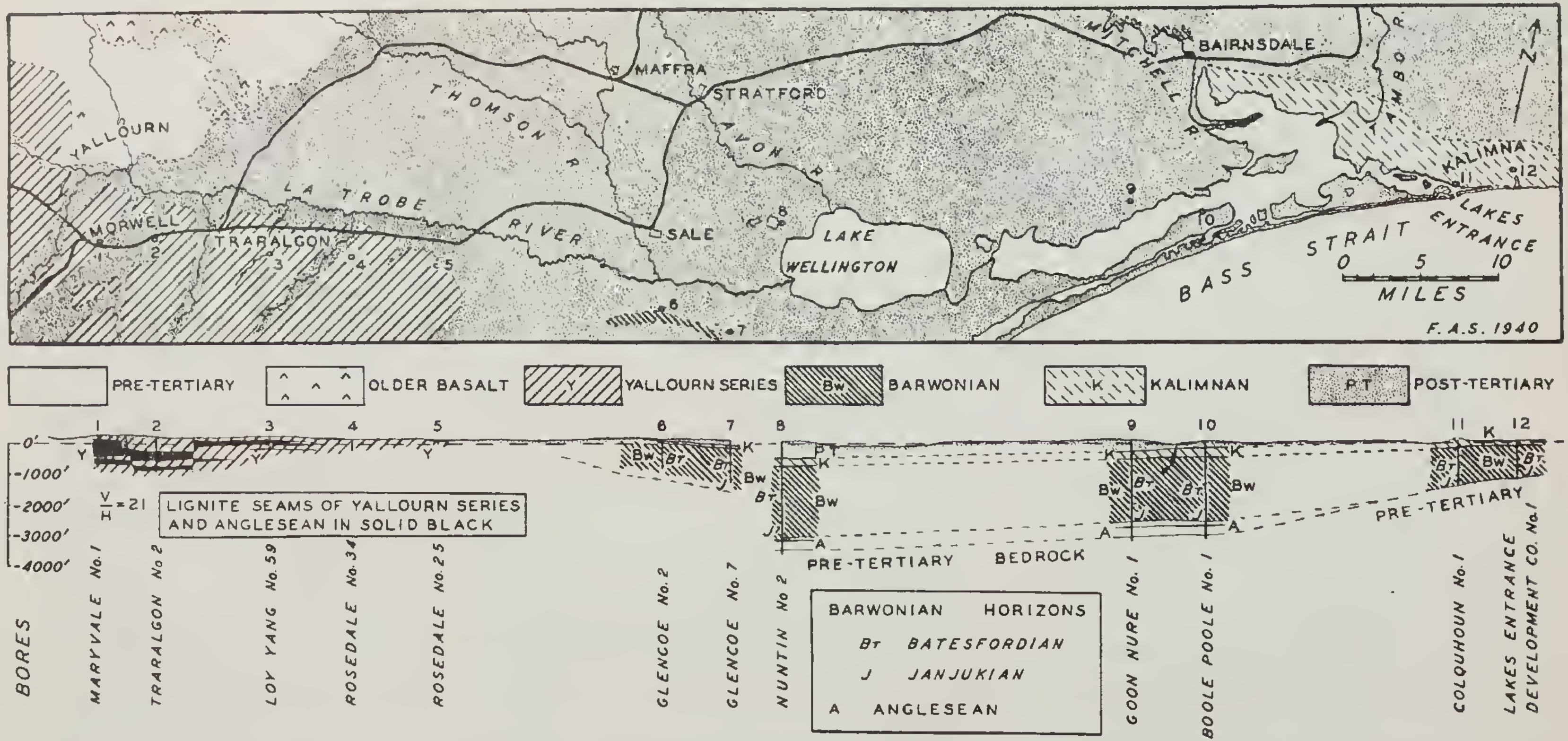


FIG. 15.—Geological map of part of East Gippsland, Victoria, and sections in the Latrobe Valley (bores 1-7) from Morwell to 4 miles E. of Longford and in the Gippsland Lakes area (bores 8-12) from Lake Kakydra to Lake Bunga. Modified from Geological Survey of Victoria maps and boring records (36, 38, 39, 40, 41, 624).

(Anglesean?) before reaching bedrock at 3,480 feet. In any case the rate of accumulation of lignites is probably greater than that of the marine sediments, and even the upper part of the Yallourn series is unlikely to be younger than the lowest part of the Barwonian (*supra*, pp. 50, 57), while the main portion is probably approximately equivalent to the Anglesean.

The general relations in the East Gippsland Tertiary basin are shown by two sections in fig. 15. The bores in the Parish of Glencoe did not reach bedrock, but showed equivalent Tertiary horizons at a much higher level than in the Lake Kakydra bore (Nuntin No. 2) which is probably near the deepest part of the Tertiary basin. This difference of level may well be accounted for by the strong northerly dip shown by Parish of Glencoe borings Nos. 1–5 and by outcrops at Le Grand's Quarry, Longford, in the same Parish.

The lignitic series to the north-west of Port Phillip from Altona to Parwan underlies Balcombian fossiliferous marls and is thus pre-Middle Miocene, but the lower limit of age is uncertain. At Altona an early boring is said to have encountered shells in "fine white quartz-drift" below the brown coal (108, p. 218; 648, p. 82).

Borings (38, pp. 42, 57) south-west of Parwan (Parish of Mouyong, Nos. 2 and 6) have penetrated a 6-ft. lignite seam with fossiliferous marine strata above and below: unfortunately, these faunas have not yet been studied. Beneath in No. 2 bore is a thicker lignite probably correlable with that of Altona.

Small seams of lignite occur, as above noted, beneath the marine beds of the East Gippsland basin south of Sale and of Bairnsdale, in the Tyabb bores (36, p. 28), and a 15-ft. seam beneath the type Janjukian in Torquay bore No. 4 (38, p.17).

In South Australia the Moorlands lignite (613, 640) also underlies marine Barwonian. The only lignites that come into direct relation with probable Lower Pliocene marine rocks are near Gelliondale in South Gippsland, where they underlie a marine fauna referred by Chapman and Crespin (26, p. 120) to the Kalimnan. Thus they are pre-Kalimnan, but how much older is uncertain.

Though all these occurrences of lignites are not necessarily on the same horizon, in general they agree in being antecedent in the main to the principal or Barwonian marine deposits, and it is therefore not unreasonable to refer the bulk of the lignitic series to the Oligocene.

### *The Relations of the Older Volcanic Series.*

Where the Older Volcanic series or Older Basalts come into relation with Tertiary marine rocks, they are usually unconformably overlain by Janjukian, Batesfordian or Balcombian deposits (*supra,* p. 53), except at Maude, where the older volcanic rocks occur between the lower and the upper Maude beds.

*Airey's Inlet.*—At Eagle Rock and Split Point near Airey's Inlet (102, p. 49), the eroded surface of basalt flows and tuffs of the Older Volcanic series is overlain by bryozoan limestones which have been correlated (102) with the limestones of the Upper Janjukian of the type section. It is, however, possible that the horizon may ultimately prove to be lower in the Janjukian stage. It may be noted that none of the deep borings at the type locality (38, pp. 15–17) encountered basalt.

*Flinders.*—Bryozoan limestone with *Lepidocyclina* and calcisponges rests on the eroded surface of "Older Basalt," which is here of great thickness, though locally there intervenes a thin conglomerate of basaltic pebbles. The section given by Chapman (23, p. 33) is in error in showing the limestone as Janjukian and the overlying material as decomposed Newer Basalt. The former is Batesfordian and the latter, as correctly shown in Kitson's section (137), is clay washed down from weathered Older Basalt at a higher level. Newer Basalt is unknown on Mornington Peninsula.

*Keilor.*—At Green Gully near Keilor, a small exposure of Batesfordian limestone (77) rests directly on Older Basalt and is itself overlain by ironstones with a shelly fauna probably of Balcombian age (17, 108).

*Royal Park.*—In the railway cutting south-west of Royal Park station (108, 158), the eroded surface of Older Basalt is overlain by ferruginous sandstones and ironstones with a fauna similar to that of Keilor and like it referred by Hall and Pritchard and the writer to the Balcombian, but by Chapman to the Janjukian.

*Mornington District.*—At Grice's Creek, Hall and Pritchard (111, pp. 39, 44) described the Balcombian clays as dipping at a high angle towards the basalt and then at a still higher angle off it, and regarded the igneous rock as the older. The writer agrees with this sequence, but believes the dip of the clays, as shown by the intercalated concretionary limestones, to be uniformly away from the basalt in a downstream direction: the junction is obscure and may be due to faulting.

Chapman, however, gave a generalized section (23, p. 30) showing the basalt as intercalated between the Balcombian clays and an overlying ferruginous series referred by him to the Janjukian (59), a correlation above criticized (p. 77).

At Balcombe Bay the Older Basalt is exposed at the first point south of the Cement Works, but its relation to the Balcombian clays north of the Cement Works is obscure, and little light is thrown on it by Hall and Pritchard's (111) and Chapman's (23, p. 26) sections. The writer believes a fault with northerly downthrow intervenes between this point and the cement works. Decisive evidence as to the position of the basalt beneath the Balcombian at its type locality has since been furnished by Parish of Mooroodue bore No. 6 (36, p. 30, and *supra*, p. 27).

*Curlewis.*—Here also, as first shown by Hall and Pritchard (105) and recently confirmed by Coulson (76), the Older Volcanic tuffs and basalt are antecedent to the Tertiary clays and bryozoan limestone, and not younger than them as originally supposed by Daintree (79), whose sketch section has been reproduced by Chapman (260, p. 215). The last-named author (23) agreed with Daintree in placing the main volcanic series above the limestone, but regarded the underlying blue clay as itself resting on an ash bed, the clay and limestone being referred to the Janjukian. The fauna of the clays is, however, Balcombian, and the whole of the volcanic rocks pre-Balcombian.

*Maude.*—The occurrence of a considerable thickness of basalt between marine Tertiary beds in the valley of the Moorabool River near Maude (*supra*, p. 70, and fig. 12) has been admitted by all observers. There is, however, disagreement as to the age of the overlying marine strata, the Upper Maude beds having been referred by Hall and Pritchard (112) to the Balcombian and by Chapman (23) to the Janjukian, and as to whether there is a second flow of basalt intercalated in the lower part of the Upper Maude beds.

On Quarter-sheet No. 19 S.W. of the Geological Survey of Victoria, 1865, mapped by C. S. Wilkinson and R. A. F. Murray, a thin limestone is shown within the upper part of the Older Volcanic series, but Hall and Pritchard (106) were unable to find any evidence of it in the field. Chapman (23, p. 42), however, claimed this could be seen below Maude township on the Knight's Bridge road. After examination of this section and others in the district, the writer unhesitatingly supports Hall and Pritchard's view. At the spot cited by Chapman and immediately north of the outcrop on the Knight's Bridge road of the hard bryozoan limestone of the Upper Maude beds, there are two small excavations. In the upper quarry 2 ft. 6 in. of cross-bedded bryozoan limestone rest on 1 foot of hard bryozoan limestone, and this upon very decomposed basalt. Between this exposure and the road the lower quarry shows basalt, vesicular at the base, at a lower level. In neither case is the lower limit of the basalt visible, and Chapman's belief in an intercalated basalt flow 18 inches in thickness may be due to his having produced laterally two basalt-limestone contacts at different levels. The alternative view of the writer is that the eroded surface of the basalt, on which the limestone rests, is a very uneven one.

Other traverses on the left bank of the Moorabool River also fail to show any trace of a later flow of Older Basalt, enclosed within the Upper Maude beds. In some of these traverses the marine Tertiary beds are underlain by varying thicknesses, from a few feet upwards, of non-marine sandstones or pebble beds (16, 23, pp. 40, 41). These appear to be absent in the second gully north of the Knight's Bridge road, where the sequence, with approximate thicknesses, is from above—

Upper Maude beds (52 feet).
- Sandy marls with calcareous concretions and a ferruginous grit band about 10 feet from top (36 feet?).
- Hard limestone, bryozoan in lower 2 feet (15 feet?).
- Basaltic pebble bed (1 foot).

Older Basalt (80 feet).

Lower Maude beds (65 feet).
- Sandy rubbly limestone (20 feet?).
- Fine bedded sandy limestone (8 feet?).
- Massive sandy limestone (12 feet).
- Fine sandy marls, with some discontinuous pebble bands (25 feet).

Ordovician slates and sandstones.

Succeeding the Upper Maude beds immediately to the north of Maude township is Newer Basalt of about 50 feet thickness, overlying marls and a hard sandstone, which are possibly to be separated from the Upper Maude beds and to be referred to the Pliocene.

The Older Volcanic rocks of Maude are thus, in the view of Hall and Pritchard and of the writer, post-Janjukian and pre-Balcombian; those of Airey's Inlet are at latest pre-Upper Janjukian. Whether those of Curlewis and Mornington, which are overlain by Balcombian marls, are to be correlated with those of Maude or with those of Airey's Inlet, as is here done, remains uncertain.

## Summary.

Marine Tertiary formations form a discontinuous fringe along 5,000 miles of the west and south coasts from North-West Cape in Western Australia to near Lakes Entrance in Victoria, and in N.W. Tasmania. Differing views as to their classification in S.E. Australia have been expressed by McCoy and the Victorian Geological Survey, by Tate and Dennant, by Hall and Pritchard, and by Chapman and his associates.

To the Upper Eocene are referred *Discocylina* limestones in the Giralia Range at the head of Exmouth Gulf, and elsewhere in N.W. Australia; and perhaps also shales with a faunule of smaller foraminifera from deep borings near Perth, in S.W. Australia. Probably Upper Oligocene are *Eulepidina* limestones in the N.W. Cape Range and the earliest marine strata of S.E. Australia. Chiefly Lower to Middle Miocene is the main development of marine Tertiary strata, including *Nephrolepidina* limestones as well as richly fossiliferous clastic sediments, and several stages may be recognized in Victoria, where Upper Miocene may also be present. Marine Pliocene beds, in at least three stages, occur in S.E. Australia.

The marine stages, which are formally defined and whose stratigraphical relations are discussed, are from older to younger, Giralian, Anglesean, Janjukian, Batesfordian, Balcombian, Cheltenhamian, Kalimnan, Adelaidean, Werrikooian, with probable new stages to be interpolated before and after the Anglesean and between Adelaidean and Werrikooian.

Correlation with adjacent countries is not far advanced, but foraminiferal faunules indicate that stages *b*, *d*, *e*, *f* of the Netherlands East Indies are represented in Australia. Only approximate correlation with stages in New Zealand is as yet possible.

Non-marine deposits occupy wide areas, especially in the interior, but are difficult to date except in the south-east, where they come into relation with marine deposits. Important lignites, chiefly Oligocene, are developed notably in Victoria. Other deposits, mainly fluviatile or lacustrine, may be tentatively referred to various horizons from Eocene to Pliocene, but can seldom be satisfactorily correlated, since the terrestrial vertebrate fauna is almost unrepresented prior to late Pliocene times.

Igneous rocks, largely basaltic, but including alkaline and acid lavas and intrusions, are well developed on horizons from at least early Oligocene to late Pliocene. The basic lavas are chiefly tholeiites in Western Australia and olivine-basalts in Eastern Australia, where more alkaline types include olivine-nephelinites, leucite-basalts, trachyphonolites, tinguaites, trachytes, and solvsbergites, while acid lavas, rhyolites, pitchstones, and dacites, occur mainly in S.E. Queensland. Perhaps Tertiary, are the leucite-lamproites of the Kimberley district, N.W. Australia.

Diastrophism, thought to be late Miocene or Pliocene, has folded Tertiary rocks in N.W. Australia, where, in the Cape Range anticline, marine Tertiary rocks have been upwarped to 1,200 feet above sea level. In S.E. Australia the marine Tertiary deposits, though commonly nearly horizontal, in places show gentle folding with dips of 10°–20°, while locally they may even be vertical where involved in fault movements. Downwarping has permitted marine transgression, reaching a maximum in Miocene times, to distances from the present coastline of 250 miles in the Murray River basin and probably nearly 200 miles in the region north of the Great Australian Bight. In such downwarped areas lignites totalling 780 feet in thickness occur in the Latrobe Valley in Victoria, while in other areas marine Tertiary deposits reach thicknesses of more than 2,500 feet. Elsewhere block-faulting has raised them to 900 feet above sea level.

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Fig. 1.—Anglesea, V. (Anglesean). Fig. 2.—Balcombe Bay, V. (Balcombian). Fig. 3.—Batesford, V. (Batesfordian).



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FIG. 1.—BEAUMARIS, V. (CHELTENHAMIAN). FIG. 2.—TORQUAY, V. (JANJUKIAN).
FIG. 3.—KALIMNA, V. (KALIMNAN).

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Fig. 1.—River Murray, S.A. (Murravian). Fig. 2.—Glenelg River, V. (Werrikooian).
Fig. 3.—Yallourn, V. (Yallourn Series).

## Explanation of Plates.

### Plate I.

Fig. 1.—Coastal cliffs between Demon's Bluff and mouth of Anglesea River, half a mile east of Anglesea bridge, Parish of Jan Juc, Victoria: type locality of Anglesean Stage. View N.E., showing dark Anglesean sandstone overlain by white sands, with rock stack in foreground and anticlinal axis hidden in bay behind projecting point. (See p. 25.) F.A.S. Photo.

Fig. 2.—Coastal cliffs 150 yards north of old cement works, Balcombe Bay, a mile and a half south of Mornington, Parish of Moorooduc, Victoria: type locality of Balcombian Stage. View S., showing grey marls (*k*) with concretionary limestone bands in lower portion, overlain by ferruginous sandstone (*p–l*) near top of cliff. Fossiliferous beds (*i*) outcrop chiefly on beach floor between fallen blocks of sandstone. (See p. 27.) F.A.S. Photo.

Fig. 3.—Upper quarry of Australian Cement Ltd. on left bank of Moorabool River, a mile south-south-east of Batesford, Parish of Moorpanyal, Victoria: type locality of Batesfordian Stage. View E.N.E., before diversion of river across quarry floor, showing Batesfordian Lepidocycline limestone (*a*) passing up into white bryozoan limestone (*b*) overlain by darker earthy limestones (*c*). At level of upper talus band these are overlain by Balcombian clays and marls (*d*), followed at the top by ferruginous sands (*e*) (Kalimnan?) white sands (*f*) (Werrikooian?) and a capping of basalt (*g*) in right upper corner. (See p. 31.) F.A.S. Photo.

### Plate II.

Fig. 1.—Coastal cliffs 150 yards east-north-east of site of former baths (marked by piles), Beaumaris, Parish of Moorabbin, Victoria: type locality of Cheltenhamian Stage. View W.S.W., showing hard band of sandstone in right foreground, under which is a shell-bed (marked by figure near rucksack), with nodule bed about 2 feet below beach level. Lower part of cliff is of fossiliferous sandstone (*a*) followed by sandy marl (*b*); upper part of hard ferruginous sandstone (*c*) capped by white sands (*d*). (See p. 33.) Nodule bed outcrops on beach floor from site of baths to far side of boatshed, the anticlinal axis being in line with hotel on cliffs. From boatshed to Table Rock in extreme distance cliffs are of ferruginous sandstone, with Lovenia bed in lower third, capped by white sands at top. F.A.S. Photo.

Fig. 2.—Coastal cliffs opposite Bird Rock (rock stack on left), one and a half miles south-west of mouth of Spring Creek, Torquay, Parish of Jan Juc, Victoria: type locality of Janjukian Stage. View S.S.W., showing sandy marls from base up to capping of Bird Rock, followed by glauconitic clays ("Chione clays") forming ledge at base of cliff on right, in turn overlain by clays and limestones of upper beds. (See p. 39.) F.A.S. Photo.

Fig. 3.—Road-cutting immediately west of bridge over North Arm, half a mile east-north-east of Jemmy's Point, Kalimna, Parish of Colquhoun, Victoria: type locality of Kalimnan Stage. View W., showing, from above, post-Kalimnan sandy clays (*l–j*), white upper shell bed (*h*) resting on hard sandstone (*g*) and sandy marls with harder bands (*f*). Hard band (*e*) reaches road level at foot of figure. Underlying beds are obscured by talus, but outcrop, including lower shell bed (*c*), to right of limit of photograph. (See p. 41.) F.A.S. Photo.

### Plate III.

Fig. 1.—Cliffs on right bank of River Murray, half a mile above Morgan, near North-West Bend, South Australia. View N.N.W., showing calcareo-argillaceous sandstones and arenaceous limestones of Middle Murravian, overlain near top of cliffs by Upper Murravian sandstones and capped by oyster beds. (See p. 43.) F. A. Cudmore Photo.

Fig. 2.—Caldwell's Cliff, eastern end, on right bank of Glenelg River, a mile and three-quarters south of Limestone Creek junction, Parish of Werrikoo, Victoria: type locality of Werrikooian Stage. View W.S.W., showing from above, flaggy and concretionary limestone (*i–c*) overlying Werrikooian shell bed (*b*) resting unconformably on Barwonian bryozoan limestone (*a*). See p. 47.) F.A.S. Photo.

Fig. 3. State Electricity Commission's Open Cut, Yallourn, Parish of Narracan, Victoria. View S.E., showing 200 ft. lignite and 30 ft. clays and sands of Yallourn Series. (See p. 48.) State Electricity Commission Photo.